Trilobite, Dinosaur and Man

The Earth's Story

by CLIFFORD D. SIMAK

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BY CLIFFORD D. SIMAK

St. Martin's Press, New York

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TRILOBITE, DINOSAUR AND MAN

The Earth's Story

1. ONCE THERE WAS NO EARTH

NOTHING ON EARTH is where or what it is by chance. There is a reason for every hill and valley. There is an explanation for the mountain chain and the lake. Each kind of soil, each rock, has a history if it can be read.

Upon our earth today we have the sum of all that has happened in the past. Very little is the same today as it was yesterday, and almost all will be different tomorrow. Land surfaces are changing all the time. Over long periods of time the changes are very great, indeed. The continents take on different shapes; the seas shift about; layers of rock deep within the earth are pushed upward, bent and twisted, into mountain ranges, and in time these mountains are worn away by weather. Land areas sink and sediments flow into the area and in time these sediments are turned into rock, and eventually the rocks may be thrust up again into new mountain chains. Lack of moisture turns once-fertile areas into desert. Lush jungles thriving in a streaming swamp are slowly turned to coal. All about us are the records of the ancient rain and wind, the frost and snow and ice, the running water, the great upheavals and the weathering, the long and slow subsidences.

Geology is that science which studies the earth. Involved in

Stratification of rock is plainly visible at Bryce Canyon, Utah. Horizontal "bands" indicate separate layers of sedimentation. Rugged terrain is product of erosion.

the study is an attempt to reach an understanding of our planet's structure and composition, the various stages through which it has passed, those natural processes and mechanisms which are continually at work to alter it, and the development of life upon it.

In all its aspects, geology tends to become a rather specialized science. It is divided into a number of branches. *Physical geology* is the study of those forces and processes which act upon the earth. *Petrology* is the study of rocks and minerals. *Economic geology* deals with the characteristics of minerals and other resources. *Geomorphology* is concerned with the shape of the earth's surface. *Stratigraphy* is the study of the

formation and position of the rock strata (layers). *Structural geology* involves the forces which deform the rocks of the earth's crust. *Paleontology* deals with the study of fossils and of life upon the earth in ancient eras. It has a subdivision, *paleobotany,* the study of fossil plant life. *Geophysics* is the study of the earth's interior by the use of physical principles. *Geochemistry,* as its name implies, is the study of the chemistry of the rocks and soils.

Historical geology—the branch of geology with which this book is concerned—is an attempt at the orderly understanding of what has happened to the earth in the past and the development of life upon it. Properly, historical geology "begins" at a time when there was no earth, no solar system, and no galaxy. How long ago this might have been, no one knows for certain.

The *evolving universe theory* says that the "big bang" which created the universe took place ten billion years ago. According to this theory, all the material in existence, through some mechanism which is not yet understood, had gathered together into one great mass which is called, for want of a better term, the cosmic egg.

The material in the cosmic egg was so closely packed together that "matter" as we ordinarily think of it could not exist. The temperature within the mass could only have been measured in the billions of degrees, and the density must have been so great as to be unimaginable. Under such conditions, atoms could not form. Nothing but radiation could exist.

And yet, say the advocates of this theory, within this seething collection of radiations there already existed the components of the particles which in time would become the earth. But there is still no clue as to when all this material might have come into being or how it had collected into one great mass—or why.

Of course, the materials of the cosmic egg must have formed somewhere and at some time. The evolving universe theory says that there was a beginning, and will be an end.

But no one yet knows how long a time was required for all this material to gather into the cosmic egg, or how long it remained within the mass before being triggered into explosion. And even the estimate that the explosion which gave rise to the universe (and, eventually, the earth) happened some ten billion years ago, is really only a guess.

But at some time, at some moment, the mass exploded, and its materials hurtled outward in all directions at a tremendous rate of speed. This was the "big bang." Once the mass had exploded, the temperature dropped almost immediately to something like a billion degrees, and continued to drop. With the reduction in temperature, atomic nuclei formed, electrons fell into place around the nuclei, and some of the lighter elements came into being (the heavier ones formed later). But to start with, there was no solid matter. All the elements first had the form of gases.

The gases and the radiations fled outward into space, traveling under the momentum of the explosion. That motion still is going on. Everything in the universe, apparently, still is moving outward from the center of that ancient explosion.

As time went on and the temperature continued to drop, some of the heavier elements began condensing out as solid matter and now there was dust in the universe as well as gas. At the end of some 30 million years the temperature probably had fallen to 80 degrees Fahrenheit, and the material which in the cosmic egg had glowed blindingly bright had become cold and dark.

Gases resulting from any explosion have a tendency to spin, and the gases that had been flung out by the explosion were spinning. As they spun they sucked in the dust. Because of this, as time went on, the clouds of spinning gas became denser. As the density of the clouds increased, they spun faster and faster. As they spun faster, they contracted, squeezing together so that their mass became even greater.

With the increase in mass, gravitational forces increased and pulled the dust-and-gas accumulations even closer together. Within the vast clouds of spinning dust and gas, innumerable small eddies began to form. As gravitational forces compacted the eddies, pressure within them began to rise.

As the pressures rose, the cold eddies began to heat up. In time they became so hot they glowed. Finally, when the temperatures inside the steadily contracting globes had reached 20,000 degrees or so, the globes became shining spheres and the stars were born.

Not all of this happened at once. It took time. The first star probably was born some 300 million years after the big bang. The stars did not all come into being at the same time. Within the great dust-and-gas clouds that were the galaxies, the stars shone out one by one until billions of them were shining.

Five billion years or more ago, one particular star was born. It was an ordinary star. There was nothing about it to distinguish it from billions of other stars of the same size and type. But to us this one star is important, because it is our Sun.

The evolutionary theory, however, is not the only one which attempts to explain the universe. One other theory also has gained some measure of acceptance in the scientific community: the *steady state theory*. It maintains that there always has been a universe and that there always will be one. It says that there was not a beginning, and will not be an end.

According to the big bang theory of the evolving universe, the universe is still expanding, the galaxies rushing away from one another at speeds that may be, in some instances, as much as half the speed of light. (The speed of light is 186,000 miles a second.) In time, says the big bang theory, this outward fleeing of the galaxies will slow down and finally everything will come to a standstill. The stars will flicker out and all matter will be dead, all energy expended. That will be the end. The universe was born. It evolved. It will die.

It is supposed by the steady state universe theorists, however, that the universe will not die, but will continue to exist forever in time and space, which also had no beginning and shall not have an end. The steady state universe, say its advocates, is in continuous existence. Matter, they theorize, is being constantly created throughout the universe, and as the galaxies move into infinite space, the space between them is filled by new galaxies formed out of newly created matter. Thus no part of space will be left empty by the receding galaxies, but the distribution of the galaxies throughout all of occupied space will be uniform. While the universe according to this theory is eternal, it is in fact being continuously created.

It may be that the formation of this new matter, which probably takes the form of hydrogen, is what is causing the galaxies to recede. For, says the steady state universe theory, the creation of new matter may tend to create new space and it is this new space, piling up between the galaxies, which forces them apart.

One estimate is that new matter is being created at the rate of 500 atoms of hydrogen per cubic kilometer per year. (A kilometer is about five eighths of a mile.)

At this rate, it would take a long time to create enough new matter to form a new galaxy. But there is no hurry. Given enough time and enough space, the material for a new dust cloud that could become another galaxy is not only possible, but inevitable.

Once the new dust-and-gas cloud were formed, the stars then would be born and evolve in exactly the same manner as they would under the theory of the evolving universe.

So to us it makes little practical difference. Under either theory, the Sun would have formed.

Over the years many theories have been advanced concerning the formation of the solar system. Many of these now have been abandoned. None is entirely satisfactory.

But it is generally accepted that our solar system developed from a dust-and-gas cloud in much the same way that the galaxies formed. The cloud of dust and gas could have been one which surrounded the Sun at the time the Sun was formed —the dust and gas that were left over from the formation of the Sun. Or it could have been a cloud which the Sun picked up in its traveling through space.

The theory now generally accepted is the one advanced in 1944 by Carl von Weizsacker, of Germany.

His theory says that the dust-and-gas cloud surrounding the Sun broke up into a number of small eddies and that these eddies in time condensed into the planets and the other bodies of the solar system.

The principal reason for the acceptance of the Weizsacker theory is that it explains, in part at least, the problem of angular momentum in the solar system. The planets and the other matter in the solar system account for slightly less than one tenth of one per cent of the system's entire mass. The rest of the mass is within the Sun. Yet this one tenth of one per cent has almost 98 per cent of the angular momentum in the system. The Sun, instead of rotating once every 27 days, should be making one revolution every 12 hours. But this simply isn't the case. Most of the spin in the solar system lies in the bodies which orbit the Sun.

Weizsacker's theory states that friction between the eddies of dust and gas upset the angular momentum function. The faster-moving inner portions of the forming solar system slowed down under friction and the more slowly-moving outer portions speeded up. Angular momentum, in other words, was transferred out from the center.

This is an explanation which still leaves a good deal to be desired. But it is a problem for the physicist rather than the geologist.

What is important is that, by whatever mechanism, the solar system did come into being. Finally, after many millennia, those

component particles which were destined to become the planet earth had accomplished their purpose. They had traveled a long way before they found a place to settle down.

Through billions of years the processes of creation had been pointed toward many ends. One of these ends turned out to be our solar system. Third out from the Sun swung a brand new planet, raw and savage, and perhaps in a molten state, although of that we cannot be certain.

The best estimate at the moment is that the earth was formed about five billion years ago. If this is true, then we are faced with a blank period in its history extending over more than a billion and a half years.

The oldest rocks known on earth are dated at 3.4 billion years. These have been found in the Johannesburg area of South Africa and in Karelia, the northwestern province of the Soviet Union. The oldest rocks in the North American continent are the Morton gneisses in southern Minnesota, which date back to 3.3 billion years ago.

Somewhere, older rocks must still exist. But they may be buried under later (and therefore, younger) rocks and may be impossible to find.

Just when the first rocks were formed would depend upon when the crust of the earth was formed. The date for the formation of the crust, in turn, would depend upon whether the earth passed through a molten state. Until a few years ago it was generally accepted that the earth at one time had been entirely molten. Now, however, there is some question about it.

But even if the earth were not molten in its early stages, there is no question that it was hot. The heat could have been supplied by the compression of gravity which pulled the planet into shape. Another source of heat could have been radioactivity. The earth today has lost a great deal of its radioactivity. It has had some five billion years to get rid of it. In the beginning, however, radioactivity would have been a major heating factor.

It is very probable that all the planets originally were much larger than they are at present. The heavier materials collected in the center of the primitive masses which became the planets, leaving an extensive atmosphere of lighter gases around the central condensation. These were the so-called proto-planets.

Radiation pressure from the Sun would have blown away the greater part of these early extensive atmospheres. The smaller planets, such as earth, would have lost additional mass through the escape of lighter gases because of the lower escape velocity resulting from these planets' lower gravity. The larger planets, such as Jupiter, because they were more massive and had a higher escape velocity, would have been able to retain a larger part of their primitive atmospheres.

So here we have the earth in its final size, with its massive early atmosphere stripped away. What remained of its atmosphere was a deadly mixture—ammonia, carbon dioxide, carbon monoxide, methane gas and water vapor. There would have been little or no free oxygen. There was oxygen, of course, but it was tied up in combination with other elements.

As the years passed the earth's surface cooled and tended to harden. But beneath the surface a great commotion was taking place. This commotion might be compared to what goes on inside a blast furnace. The different metals were sorting themselves out. The heavier metals were sinking to the central core, while the lighter material was rising to the surface as slag rises to the top of the furnace. And riding to the top of it all, to the outer crust, was the rock that we know today as granite. For while granite is heavy, it is the lightest of the basic rocks.

How long it took the crust to harden, no one knows. Thousands of years, most certainly; perhaps as many as a million. It would have hardened sooner had it not been for the sorting-out process which was taking place within the earth's interior.

As the crust cooled and hardened, great streams of hot

Once common, volcanoes are now a rarity. In 1963 a new volcanic island, named Surtsey, erupted off the coast of Iceland. Island has attracted hundreds of scientists.

material came surging up from underneath, exactly like the fluid movement in a pan of boiling water. Time and time again the newly-formed crust was broken as the hot material found a weak spot and forced its way upward to flow across the surface. Possibly, before the crust could finally form, some crystallization of materials occurred beneath the surface, sealing in the hot metallic core.

During this period the earth was a truly fearsome place. Huge streams of molten material flowed across its crust. Great spouts of water vapor and carbon dioxide gushed from cracks and fissures. Flames shot into the sky from erupting volcanoes, and smoke rolled across the landscape. Meteorites came thun-

dering down out of the sky to splash into the pools of molten metal or to punch into the crust. There were many more meteors then than today. In that early era the solar system was full of all sorts of junk left over from the process of planet-making.

But finally the crust did form. Streams of molten material still flowed out of fissures to form new lava fields. Volcanoes spouted, filling the air with ash, releasing gases to feed the atmosphere. But the crust was there. It had gained the upper hand.

While all of this was going on, the atmosphere was building. Water vapor poured out of the interior of the forming planet and collected in massive clouds that covered the entire face of the earth. For a long time, perhaps for several thousand years, no sunlight fell upon the earth as the billowing clouds surged above the barren landscape.

At times rain fell from the higher clouds, where the temperature was cooler. But before the rain could reach the surface, it was turned to vapor by the heat: the temperature was still far above the boiling point of water.

The surface might have cooled in a shorter time had it not been for the clouds, which formed an insulating layer between the heat of the young earth and the cold of space.

Even so, however, the atmospheric temperature fell as the earth cooled off. Finally, on some unrecorded day, the surface temperature fell below the boiling point of water and rain was possible. The rain started to fall and it did not turn to steam. For centuries it rained, never stopping for a moment. It may have rained for a thousand years.

The falling of the rain hastened the cooling of the crust, and in time the clouds had emptied themselves of all the water vapor that had been collecting for so many centuries. The Sun finally shone again upon the surface of the earth. Sparkling in the rays of sunshine were something that was entirely new to earth—great shining sheets of water.

The fallen rain collected in low places, forming lakes and

oceans. Running water had carved out stream beds as it flowed in raging torrents during the centuries through which the rain fell.

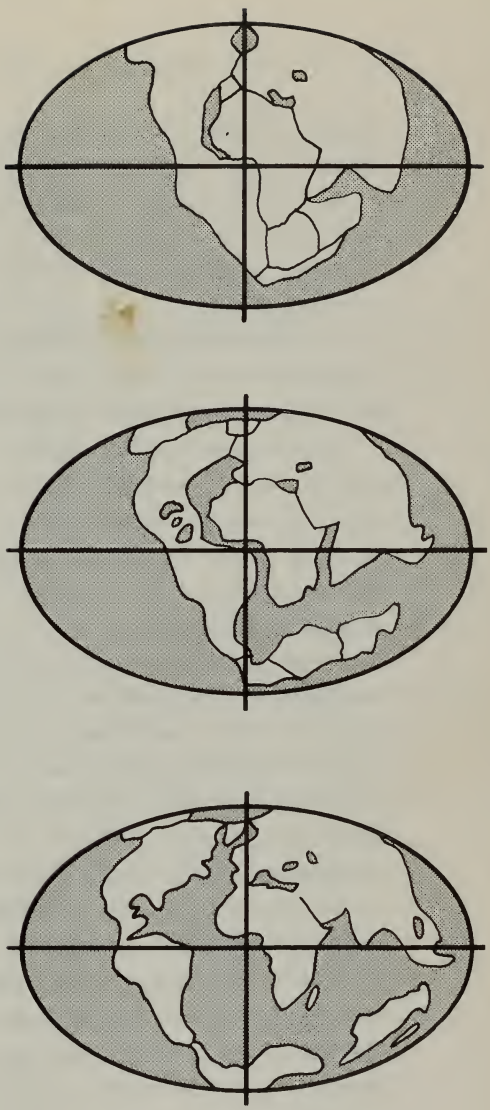
But the earth was still a fearful and a barren place. As yet there was no life of any sort. There was no spear of green, nothing that moved of its own volition. The rocks lay bare, as they would for millions of years.

Even before the rains had fallen, the primitive atmosphere had attacked the surface rocks, beginning that long process of erosion which continues to this day. The rains sped up the erosion. Working together, air and water ate into the rocks, sculpturing the landscape.

The process of interior cooling continued and there were volcanoes and lava flows, the spouting of geysers, the hiss of gases escaping from the earth. Water vapor rose from the surface of the newly-formed bodies of water and new clouds formed and new rains fell.

At first, perhaps, the lakes and the oceans were not as extensive as they are today. There may have been no more than 20 per cent of the water now present on the earth. But as the years rolled on, more water vapor would be expelled from the earth's interior, and over millennia this would be added to the water budget until we have our present quota.

There is no way one can tell what the geography of this youthful world was like. It can be assumed, however, that mountains rose and were worn away. If so, their stumps lie buried deep beneath the present surface, their peaks long ago weathered away and deposited as sediment in long forgotten seas. It may be assumed that land areas rose and subsided, that seas invaded those land areas and then retreated, that the face of the planet changed many, many times. It is impossible to say exactly when the world came to have the contours we know today. Before that time, the shape of the land surfaces —the continents—as they then existed would have been entirely unfamiliar.



According to the drifting continent theory, continents were originally massed in a single proto-continent (top). Gradually, the mass drifted apart (middle, bottom). Eventually, masses formed continents as we know them today.

There are two schools of thought about the continents. One says that they congealed in virtually the exact positions they occupy today. Another subscribes to the theory of the drifting continents—a belief that the total land mass of the earth first

formed as a single mass, then split, with the various land masses drifting slowly through long ages to their present positions. Belief in this theory is supported in part, although far from conclusively, by the fact that the eastern coastlines of the two Americas would roughly fit into the western coastlines of Europe and Africa.

In order to arrive at a better understanding of those processes and events which have shaped the physical history of the earth, two particular things should be borne in mind.

The first is that the surface of the earth is comparatively smooth—much smoother than one might think. The vertical span between the highest point of land surface and the lowest depth of ocean is only 13 miles. The average height of the continents above the average depth of the oceans is no more than three miles.

Let us say that we represent the earth by a ball five feet in diameter. The continents then could be represented by a coat of varnish one fiftieth of an inch thick. Keeping this in mind, it becomes a little easier to understand the forces which have operated over the eons to shape the surface of the earth. While the complete erosion of a mountain may be hard to comprehend, comprehension becomes a little easier if we think of the mountain as only a slightly thicker coat of varnish on that five-foot ball.

The second thing which must be borne in mind, and an extremely difficult thing to keep in proper perspective, is the amount of time which has been involved in all the changes that have occurred upon the earth. Ordinarily, we deal in hours and days and years. Recorded history extends over only about 5,000 years. But geology deals in millions and billions of years. So much can happen in time spans of that length! Mountains can rise and wear down time and time again, continents can take a series of different shapes. The face of a whole world can change—and it has.

2. THE FORCES THAT SHAPE THE EARTH

THREE MAJOR PROCESSES have operated through all of earth's history to shape the surface of our planet. The same three are in operation today. They are working on the surface of the earth at this very moment, in exactly the same way they have worked ever since the world began. They will continue for so long as any energy remains within the earth or in its atmosphere.

The three processes are volcanism (sometimes spelled vulcanism), diastrophism, and gradation.

Volcanism is the melting and erupting process caused by the heat and the pressures within the earth's interior. The term itself suggests volcanoes, but not all volcanism has to do with volcanoes. It refers to any movement of molten rock material. It makes no difference whether it is hurled out of a volcano, flows out of cracks in the earth's surface, or simply forces its way upward among older rocks beneath the surface, never reaching the surface.

Most volcanism, as a matter of fact, is of the latter kind, taking place deep underground. It is revealed only when the overlying surface has been worn away to expose great masses

of this magma (molten material) which has cooled to form rock.

The larger masses of such rock are called batholiths and may cover thousands of square miles. In some cases extensive batholiths are the cores of mountain ranges.

Diastrophism is the warping, crumpling and displacement of portions of the earth's crust. It is caused by great stresses at or beneath the surface. The same processes which create large areas of the molten rock that causes volcanism, also can produce stress and pressure to bring about diastrophism, lifting mountain chains and plateaus.

This does not happen all at once. It is a slow and gradual process. A mountain is not built in a day nor a plateau lifted in a year. The pressures build up slowly until the crust no longer can withstand the strain. When this point is reached, the crust yields along some weak point. At times, when this yielding occurs, high velocity tremors are generated within the structure of the crust and travel through the rocks. This is called an earthquake.

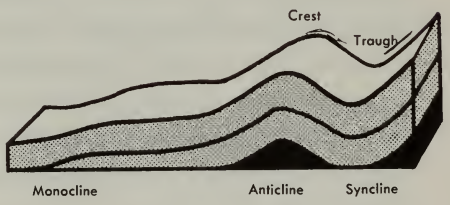
But earthquakes are not very frequent. In most instances the pressures build up slowly and the yielding is slow and gradual. Most geological changes have come about by long, slow movements of this sort.

Diastrophism usually acts in one of two ways. Epeirogenic movements (changes in the earth's crust) involve the uplift or subsidence of large areas. Uplift results in plateaus. Submergence results in epicontinental seas. An epicontinental sea is a shallow sea which creeps over the continental platform and invades a part of the continent. Throughout earth's history, many such seas have covered large continental areas. Today is no exception. Hudson's Bay and the Baltic Sea are epicontinental seas.

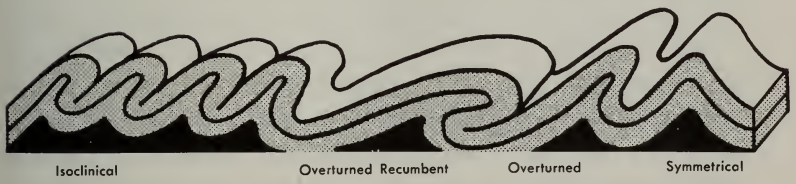
The uplift or subsidence of somewhat smaller areas is involved in orogenic movements, the means by which mountain chains are formed. We speak of orogenies, or mountain-building

periods. Orogenic movements normally are of greater intensity than epeirogenic movements. The actual deformation of the crust which takes place during an orogeny involves either the folding of the crust so that the rock strata (layers), while bent and twisted, still retain their continuity, or faulting. Faulting is a fracturing of the strata.

An upward fold, forming an arch, is called an anticline. A downward fold, forming a trough, is a syncline. When a syncline covers a large area, it is referred to as a geosyncline. An anticline covering a large area is a geanticline. Ordinarily, geanticlines and geosynclines are long and fairly narrow. But some anticlines may be dome-shaped and some synclines may be basin-shaped. Where faulting has resulted, we speak of a fault as a geological feature, a fracture that has resulted in the displacement of the rock structure in relation to the fracture surface. This displacement may be only a few feet, although in some instances it is measured in hundreds of feet.



The basic types of folds.



Anticlines and synclines vary widely.

Small, highly folded syncline in sandstones and shales.

Diastrophism is sometimes hard to understand because it is something that we cannot see happening. To us the surface of the earth is solid and substantial. It doesn't bob up and down like a yo-yo. It stays in place and, except when there is an earthquake, it doesn't move. But if we were to speed up time a millionfold, then we could notice the movement—for all of this movement, all this shifting and adjusting, is something that occurs over extremely long periods of time.

And why, one might ask, does it happen at all? Isn't the earth a solid body?

The answer to that is that earth is a solid body, but a stable one only in terms of the short time-spans which man experiences. Its surface is continually shifting and changing, responding to stresses which are far from perfectly understood. Since the pressures and stresses which cause the movement, and the movements themselves, originate beneath the surface, they are hard to assess.

Anticline in same region (Washington County, Maryland).

One theory is that the earth is still in the process of shrinking, due to a continuing cooling process, and that the crust must accommodate itself to this shrinkage. One must bear in mind, however, that this is only a theory.

Another explanation is that the earth is trying to adjust itself to the shifting of the distribution of materials caused by erosion and sedimentation. Sediments are deposited in great quantities in a given spot, and as a result that part of the crust becomes heavier and tends to sink. At the same time, the area from which these sediments have been removed becomes lighter because of the removal of material, and thus it tends to rise.

Diastrophism may be nothing more than the normal response of the crust to these varying weights, an attempt to maintain a balance.

Subcrustal movements of hot material also may contribute to diastrophism, but if we accept this as an explanation, then we

must seek specific reasons for the movement of the hot materials.

Diastrophism is something for which we have as yet no adequate explanation.

Gradation is the leveling-off process which works hand-in-hand with diastrophism. Even while a mountain or plateau is rising as a result of diastrophism, gradation is at work to wear down that mountain or plateau. And at the same time it is wearing down one place, it is filling up another. The trend always is toward a level surface.

Given time the mountain will be worn down and the low places adjacent to it will be filled. When this happens, the level surface is called a peneplain and the mountain is said to have been peneplained.

Rocks which are buried deep beneath the surface are subject to little, if any, change. If they remained buried, out of the reach of air or water, they would stay unchanged indefinitely. But rock which is exposed to either water or air, or to both, is subject to a process known as chemical weathering.

Rocks—like everything else on earth—are basically composed of chemical compounds. Chemicals interact with water and gases, and once rock is exposed, this interaction immediately begins. The interaction, the combining of chemicals in the rock with water or certain elements in the atmosphere, causes the rock structure to become less dense and less coherent.

Most chemicals have a certain degree of solubility in water. The action of water upon these chemicals is called hydration and is one of the factors involved in the breaking down of rock. Oxygen, one of the gases in the air, has a high affinity for iron and most rocks have some form of iron in their makeup. When iron is exposed to oxygen, rust results—in time a piece of iron turns entirely to rust by its interaction with oxygen. This process, called oxidation, is another factor which helps to break down exposed rock. Carbon dioxide, another gas present in the atmosphere, combines with many different

minerals to form compounds known as carbonates. Carbonates are readily soluble in water. Thus the action of carbon dioxide upon an exposed rock paves the way for water to go about its disintegrative action. We may see that rock long exposed to the elements tends to be darker or duller in color than freshly exposed rock. This darker color is the result of chemical weathering, the oxidation of iron and other minerals within the rock.

Certain mechanical processes also are involved, and in many cases are an aid to chemical weathering. Deeply buried rock is subjected to considerable pressure as a result of the overlay of other rocks or earth. When the rock is exposed, this pressure is removed and as a result the rock expands slightly. The expanded rock tends to crack or split, allowing water and air to penetrate into the rock. Even if there is no crack or split, the reduced pressure loosens the cohesion between the mineral grains which make up the rock, permitting easy access to water and air.

Another mechanical process which results in the crumbling of rock is the freezing of water. In freezing, water expands about one tenth of its volume. In a confined space it can exert a pressure of 150 pounds per square foot. While such a condition would rarely, if ever, occur in the freezing of water which has penetrated a rock through a crack or some other opening, nevertheless there is a considerable pressure exerted by freezing water even when it is not confined. Such pressures would operate, even on the smallest scale, to break down the rock or to lessen the cohesion of its mineral grains.

Alternate heating and cooling also plays some part in breaking down rock, but not nearly on the same scale as most of the other forces which are at work.

A plant sends a root down into a rock, exerting some pressure on the rock around it. But even more important is the fact that when the plant dies, the hole which was occupied by the root provides another channel by which water and air

can enter the rock and get to work on it. And the root, while it is alive and growing, absorbs some soluble material within the rock. The removal of this material makes the rock just that much more vulnerable to the action of water and air.

The first plants ordinarily to be found growing upon freshly exposed rock are the lichens, which are a combination of an alga and a fungus, living in a working partnership. The lichens also contribute their bit to the breaking down of rock. They keep the surface of the rock damp. When they die, they release carbon dioxide which serves to soften up the rock by producing carbonates. They also release certain acids which, in turn, attack the rock.

Chemical weathering is an extremely slow process, but time is one of the ingredients of geological change. Given time enough, chemical weathering alone could completely disintegrate a piece of rock. But chemical weathering is only part of the picture. Erosion is accomplished by many different factors, and chemical weathering is only one of them. Water, wind, and ice not only serve to transport the smaller parts of broken and disintegrated rock, but by abrasive action will continue to break down their size. In time any rock will become sand or soil.

And then, perhaps, in time, rock again. But that is getting ahead of the story.

Gradation is concerned not only with the leveling off of high areas, but with the filling in of low areas as well. Not only is rock broken down, but it must be transported from the higher area which it occupies to a lower area. Not only erosion and disintegration are involved, but transportation and deposition (sedimentation) as well.

Glaciers are the greatest force of all in the transporting of material, although running water is the most widespread and general agent. Winds, under certain conditions, will transport a great amount of fine material.

Water may carry material either in solution or simply by

Fan-shaped deposits at edge of Mojave Desert, California, were carried down from mountains by running water.

sweeping it along in suspension or rolling it along the bottom of the stream, transporting sand and mud and at times small pieces of rock by the mechanical energy of flowing water.

The United States Geological Survey estimates that American rivers and streams are carrying 270 million tons of material in solution into the oceans each year. Another 513 million tons are carried in the form of solid matter. At this rate, if the material were obtained equally from all areas of the nation, the level of the United States would be lowered one foot in a little less than 10,000 years. The Mississippi River, alone, each year transports 136 million tons of material in solution and another 340 million tons in suspension.

The suspension of material in some extreme instances may amount to as much as 50 per cent of the total stream. There is the old saying about the Missouri River that the water in it is too thick to drink, but that you can break off a piece

of it and suck it. Dip a glass of water out of such a stream and in a few minutes an amazing amount of sand will have settled to the bottom of the glass—sand which had been held in suspension by the water.

While running streams serve as transport agents for a great amount of material, redistributing it over the surface of the earth, rain serves to bring much of this material to the streams. The average annual rainfall over the entire earth amounts to 33 inches, about one pound per square inch. An average of 15 million tons of rain is estimated to drop upon the earth every second. The maximum speed of a raindrop when it hits the earth is 25 miles an hour. A hard rain, under circumstances ideal for the transport of material, is capable of dislodging and moving as much as 100 tons of earth per acre. This would be an extreme circumstance, of course, but it illustrates the capability which rain possesses as a transport agent.

Wind serves as an effective transport agent in dry areas. In areas of average humidity plant cover protects the soil from the effects of wind. Moisture also helps to bind loose soil particles together. But in arid areas, where ground cover is scant and there is no moisture to bind soil or sand together, a great deal of material can be transported by the wind.

The dust storms of the 1930's in the American West and Midwest are an example from our own time of how wind can serve as a transport agent. Those so-called black blizzards carried soil from the Western Plains as far as the Atlantic seaboard. Millions of tons of dust and sand were moved by a single storm. The dust storms came about as a result of over grazing or the plowing of land which never should have been plowed. With the ground cover either entirely removed or greatly decreased, and with a long drought sucking all moisture from the surface of the land, the winds were able to scoop out great areas of topsoil and carry it away. Before the white man came to the American Plains the land had been protected by a natural

covering of native grasses which had become so adapted to the land that drought had little effect upon them. The famous buffalo grass, that provided pasturage for millions of American bison, was only one of these.

The American dust bowl and the sandstorms which occur in the Sahara and other deserts are not unique in the history of the earth. In the past there have been other dust bowls and other seasons of dust storms.

During the Pleistocene glacial ages great amounts of dust (called rock flour, since it was literally flour ground out of rocks by the grinding action of the ice) were left behind when the glaciers retreated. Geological evidence tells that this rock flour was very extensively transported by the winds. In the American Midwest many fertile corn fields have as their basis the rock flour, called loess, which was distributed by the winds following the great glacial age. In those days, some thousands of years ago, mid-America must have witnessed dust storms of truly heroic proportions.

The greatest deposits of loess known anywhere in the world are in China. Here the soil is composed of this material to the depth of several hundred feet. In places the deposits may exceed a thousand feet. About half a million square miles in China are covered by the material. But the Chinese loess is not glacial in origin. Rather, through long ages, it was carried by prevailing winds from the disintegrating rocks of the Gobi Desert.

Loess is exceedingly fertile because it retains much of the rich chemical content of the rock out of which it originated.

Abrasion by wind-transported sand has produced many curious rock sculptures. The sculpturing depends upon the velocity of the wind, the amount of abrasive material it carries, and the time involved—and, also, the nature of the rock which is being sculptured. One of the better illustrations of what wind-blown sand can accomplish as a cutting agent is furnished by the windshields of cars which are subjected to long periods of

sandstorms. The glass finally becomes so pitted that it is useless.

Sand dunes are the most visible and dramatic evidence of wind deposits. The sand drifts along a surface until some of it is halted and held in place by some obstruction, perhaps a tiny obstruction, a dried weed still anchored in the earth, or a pile of rocks. Sand continues to pile up before the obstruction to a point where the sand itself acts as an obstruction. From their very small beginnings, many dunes grow to commanding sizes. Some dunes are stationary, while others are migratory. The dune migrates when the wind removes grains of sand from the windward side, sweeps them over the top of the dune, and then drops them on the leeward side. In this way the front of the dune is moved leeward, and the dune travels slowly in the direction of the prevailing wind.

Running water may carry much heavier material than wind, which usually carries only the finest of material such as sand or dust. The total amount and the size of the pieces of material carried by running water is determined largely by the velocity of the water, in other words, the power of the water. A rushing

Wind-carved red rocks of Monument Valley, Arizona, are remnants of what was once a continuous layer of rock.

stream will roll a large number of pebbles along its bottom, while a stream with a slow current lacks the power to move pebbles or gravel. As the speed of the water lessens, its transport ability also lessens. In this way it sorts out the material which it carries. The heaviest material will drop out first, and the lightest material last. Thus sediment deposited at any point by flowing water will all be the same in size. Gravel, sand, and silt tend to be deposited in separate and distinct deposits.

Wind, in the same way, will grade the material it carries. The heavier will drop out first as the wind lessens. If the wind is of sufficient velocity to carry both sand and dust, the sand will drop out when the velocity first begins to fall, but the dust will continue to be carried.

In addition to water, wind, and glaciers (which will be discussed in a later chapter), gravity also might be considered as a transport force. Gravity always works to pull any material

to the lowest level. Make a footprint in loose sand, and then watch how the sand which was pushed outward and upward by the pressure which made the footprint slowly crumbles back into the footprint. This is gravity at work, pulling back materials to a lower point. Landslides are the most dramatic examples of gravity as a transport agent. But on any steep slope where loose material is present, little trickles continually course down.

Once material is transported, it is deposited. In some instances it may be deposited several times before it reaches its final resting place. Eventually, however, all transported material finally reaches a place where it remains.

In many low places great amounts of sediment of one sort or another are deposited over long periods of years. In the course of time, these sediments grow to great thicknesses. In the case of a geosyncline, which may be continuously sinking to make way for more deposits (and sinking because of the weight of the deposits), the sediments may pile up to the depth of thousands of feet.

Under pressure, and subjected to certain chemical changes, the sediments turn into rock. And thus, a full cycle is achieved. For all sediments (all, that is, except organic sediments), no matter whether they are sand, gravel, or soil, had their first origin in rock. Now they return to rock, although in many cases rock of a different kind.

There are three classes of rock—igneous, sedimentary, and metamorphic.

Igneous is that rock which was formed by the cooling of magma, the hot material spewed up from the interior of the earth. To begin with, all rock upon the earth was igneous rock. Igneous rock still is being formed today, but not on the scale of its formation in the early days of earth. All igneous rock is the product of volcanism.

Magmas vary considerably in composition. As a result of this and because of different cooling rates, a number of different

kinds of rock can be created out of magma. The most common kinds of all are the granitic rocks.

When magma is forced to the surface of the earth, it is called an extrusion, and the rocks which form from it are called extrusive rocks.

But in many instances, the magma does not reach the surface. It stops short of the surface and solidifies there. At times the surface is eroded down to expose this rock, and the rock thus uncovered is known as intrusive igneous rock.

The texture of igneous rocks is determined by the speed with which the molten material cools. Extrusive igneous rock is fine-grained because the magma cooled quickly upon exposure to air, giving crystals little chance to form within its structure. In certain cases, the magma may cool so quickly that no crystallization is possible. There is no time for the crystals to grow. When this happens, we have what is known as volcanic glass.

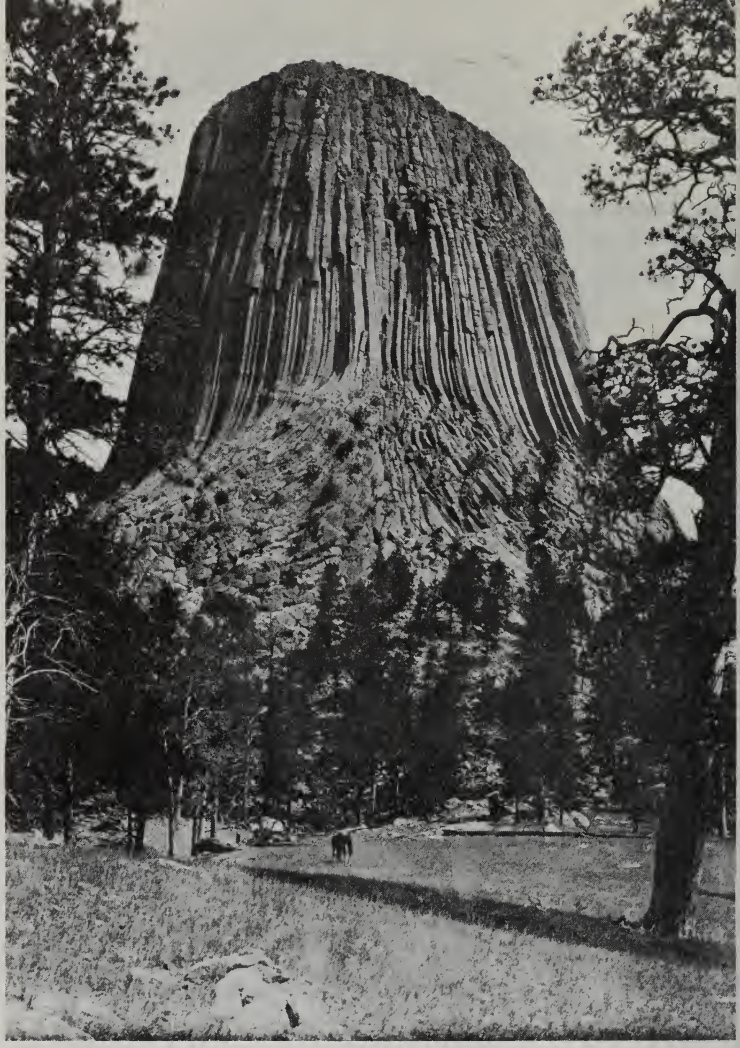
Intrusive igneous rock has large crystals and, as a result, is coarse-grained. This is because, not reaching the surface, it takes longer to cool, its heat being held in by the surrounding rock.

Granite, one of the most common rocks on the earth's surface, is an intrusive rock. The beauty of granite as a building stone is due to the formation of the large crystals, possibly because the magna out of which it solidified cooled slowly.

Gabbro is another intrusive rock, darker in color than granite. The largest mass of gabbro known in the world is the Duluth Gabbro which lies on the western corner of Lake Superior.

The other major class of igneous rock is the basaltic rocks. Basalt is an extrusive rock. It ranges in color from dark gray to black, and is so fine-grained that its crystals can be detected only with a microscope. After exposure to the air, it often turns reddish or brown. Basalt is commonly called "trap rock."

Sedimentary rocks are rocks which have been formed by the deposition of material. The deposits may have been any kind of rock debris, or they may have been the organic remains



Devil's Tower, Wyoming, is formed of basaltic rock.

of plants or animals. Peat comes from plant material. So does coal. Much limestone is formed of calcium carbonate (calcite) which has been secreted by tiny animals of the sea, usually in the form of shells.

Sediments from which the rocks are formed are laid down, usually very slowly, year after year, often at the bottoms of

lakes or seas or in river deltas. Over the course of many years, the characteristics of the sediments may change in various ways, and so they appear to have been laid down in layers.

While most rocks are formed of sediments which are laid down in water, rocks can be formed from deposits made upon dry land. Wind-borne sand, covered by later deposits, becomes sandstone. Some glacially transported material also may turn to rock after the glaciers retreat. But much of the sedimentary rock traces its origin to water, and generally to sea floors. Rocks formed by deposits on dry land are called continental formations. Those formed under seas are called marine formations.

Sediment becomes sedimentary rock by a process known as lithification. Lithification involves compaction (the result of pressure), cementation, crystallization, or a combination of all three processes.

Buried beneath tons of other sediments, at times to the depth of hundreds of feet, the earlier sediment is compacted by the weight of the material above it. Water is squeezed out of it and the individual grains are pushed so tightly together that interlocking takes place. Pick up a handful of squishy mud and squeeze it. The squeezing will force the water out. Squeeze a little harder and the mud sticks together. Compacted, the grains that make up the mud have become interlocked. The mud now is much more solid and compact than when it was scooped out of the ground. This is what happens in the compaction of sediments as the first step toward the formation of rock—except, of course, that in the case of rock formation the pressure is much greater and continues over a long period of time.

Cementation occurs when compounds in solution between the grains precipitate and act as a cement, holding the grains together. The commonest cements are calcium carbonate and hydrous iron oxide. Sometimes silica (quartz) also may act as a cement.

Crystallization occurs most commonly with very fine sediment which is held in solution with water and is precipitated out. Given time, these minerals crystallize into interlocking structures, forming dense and compact rock. This is what happens in many cases with limestone.

Sandstone, shale, and limestone are our most common sedimentary rocks. Sandstone is held together by various cementing materials. Shale is compacted clay. Conglomerate, another sedimentary rock, is gravel cemented together by a bonding material such as sand or clay. Conglomerate is often called pudding stone.

Limestone is formed of chemical or organic sediments. It is largely composed of calcite, which is held in solution by water and precipitated out of the water over the course of years. (Calcite is what makes water "hard." Water may actually be so hard that a water softening mechanism must be employed to precipitate some of the calcite out of the water before it can be used.) In the ancient seas the calcite was precipitated out of the water when its concentration built up to a point

Pudding stone (left) is a conglomerate sedimentary rock. Hornblende granite gneiss (right) is a metamorphic rock.

where it could no longer be carried in solution. Some of it was being dropped out all the time, of course, but the calcite deposits built up most rapidly during periods of heavy evaporation. Evaporation, by reducing the volume of the water, released the calcite which had been held in solution, and it fell to the bottom of the sea. When magnesium is found in any appreciable amount in the calcite, the rock is known as dolomite.

While the greatest formations of limestone mark the sites of ancient seas, limestone can form in any body of water. Marl is being formed today at the bottom of many lakes. Marl in time will become limestone. It is limestone which has not as yet been compacted and crystallized.

Some limestone also is formed almost entirely of the shells of sea creatures. Over millions of years, the little creatures died and their shells drifted to the bottom of the sea, forming a thick deposit there.

Metamorphic rock is rock that has been changed in structure, principally in its crystallization, as the result of pressure or heating. Both igneous and sedimentary rock may be metamorphosed. Metamorphism comes about when the original rock is caught in a new cycle of diastrophism. During periods of mountain-building, rock existing at or just beneath the surface is changed about and shifted. The intrusion of magma from beneath the surface will apply both pressure and heat to metamorphose existing rock.

The most common metamorphic rocks are gneiss, marble, quartzite, schist and slate. Gneisses are formed from granite as a rule, but may be formed from any igneous or sedimentary rock. They are banded, coarse-grained rock, much used as a very fine quality building stone. Quartzite is formed from sandstone, with silicon dioxide as a cement and the entire mass recrystallized. Limestones are turned to marble. Shale under pressure becomes slate. Schist is formed from slate or from a wide variety of other rocks.

Sandstone in well-defined bedding planes.

An additional classification of rock is mantle rock. While it is no particular kind of rock, mantle rock is important because it is the source of much of our soil. Mantle rock is any loose rock material which may lie to varying depths on the surface. It may be any kind of rock at all, and it results from the weathering process which breaks rock down into successively smaller pieces. As a rule mantle rock exists only in those areas where the processes of erosion do not remove it as fast as it is formed. Over the years the mantle rock breaks down further, the topmost layers breaking down first because of maximum exposure to the forces of weathering. In time, the rock will decompose and become clay, the basic constituent of soil.

Sedimentary rock is important in the study of historical

geology. Ideally it provides an exact chronology of all the geological events which have taken place upon the earth. Young rock overlies the older rock; a thick layer represents a long period of time, a thin layer a shorter period.

A geologist can read the rock strata as you and I can read the pages of a book. But often the "pages" of the rock strata are misplaced or torn or missing. It would be an easy job to read the history of the earth if all the layers of rock stood today exactly as they were laid down, but often this is not the way it is.

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The strata have been lifted and tilted and folded by continental changes and mountain building. The rocks are not where they were to start with. In some instances, where the rocks have been shifted about violently, older rocks have been shoved over young rock. In some places, the layers are entirely missing, having been worn away by erosion.

Even faced with all these problems, however, the geologist, by various means—by matching stratigraphic characters and relationships, by recognizing similarities of structural deformity, by age measurements based on radioactive dating, by a study of fossils, and by other techniques—is able, in most instances, to untangle the riddle of the rocks.

The geologist is a detective working on one of the most fascinating cases one can imagine: What has been going on since that day when the earth was formed some five billion years ago?

By a study of the rocks the geologist can tell what kind of life lived, when and how that life changed or died out, and in many cases why it changed or died out. He can determine the climates of past ages. He can trace the outlines of ancient seas and find the hiding places of long-since eroded mountains.

One by one, he wrests earth's cherished secrets from the record of the rocks.

3. HOW TO FIND THE AGE OF ROCKS

To STUDY ANYTHING, and to understand what one studies, one must have yardsticks of measurement.

The yardstick that is needed in historical geology is one that will measure, logically, large spans of time. How do you go about measuring, in an orderly and meaningful manner, five billion years of time?

Such a yardstick has existed since shortly after geology became a recognized field of scientific study. It has been only within the last decade or so, however, that theories and techniques have been developed which make possible a reasonably accurate determination of the time periods involved.

The geological time scale deals only with relative antiquity, and not with specific years. However, now that means of obtaining absolute time measurements by the use of radioactive analysis have been developed, it seems likely that within the next few decades we may be able to set up some rather solid absolute figures for the measurement of geologic time. So far there are only a relatively few absolute dates. but as the list of these absolute dates grows, something like an absolute time scale may emerge.

As it is now organized, the geologic time scale lists four

geological eras. The era is a long span of time which is broken down into smaller segments of time called periods, with the periods being broken down into epochs, and the epochs into ages. In this book, we will not be concerned with ages.

The *Precambrian* era runs from an indeterminate time up to about 600 million years ago. It is called the Precambrian because it precedes the Cambrian period, the first period in the Paleozoic era. The cutoff of the Precambrian is based upon the appearance of numerous fossils. The break between few fossils in the Precambrian era and the appearance of many fossils at the beginning of the Cambrian period is rather sharp.

The *Paleozoic* era follows the Precambrian and covers the time span from 600 million years ago until the beginning of the Mesozoic era, 230 million years ago. Paleozoic means "ancient life" and embraces the time span which witnessed the emergence of vertebrate land animals from the primitive invertebrates which lived in the earliest periods of the era.

The *Mesozoic* era (Mesozoic meaning "middle life" or "medieval life") covers the time when reptiles were the dominant form of life on earth. The era extends from 230 million years ago until the beginning of the *Cenozoic* era, which began about 63 million years ago. The term "Cenozoic" means "recent life," and applies to the period during which mammals have been the dominant form of life on earth. We still are living in the Cenozoic era.

Both the Paleozoic and the Mesozoic era are divided into periods. So also, at one time, were the Precambrian and the Cenozoic, but for general use their period designations have largely been dropped. The Cenozoic era at one time was, and for some purposes still is, divided into two periods, the Tertiary and the Quaternary. The Tertiary period included five epochs, the Paleocene, the Eocene, the Oligocene, the Miocene and the Pliocene. The epoch immediately following those earlier five, the Pleistocene, was designated as the Quaternary period.

We still are living in the Pleistocene epoch, which began only about a million years ago. Sometimes another epoch, the Recent, is added at the end of the Pleistocene, but the point at which this epoch begins has always been hazy, at best, and the inclination now is to say that we are living in the Pleistocene.

Up until a few years ago, the Precambrian was used as a sort of general designation to embrace two periods and six epochs. The first (oldest) period was the Archeozoic, which included the Keewatin, the Laurentian, the Timiskaming and the Algoman epochs. The Proterozoic period embraced the Huronian and the Keweenawan epochs. At times yet another period, the Azoic, was marked off as having preceded the Archeozoic. This breakdown still is used by some geologists, but radioactive analysis of Precambrian rocks has now so upset this system that it is being generally discarded and the Precambrian, without division into periods, is considered simply as an era, preceding the Cambrian period.

In all the foregoing the thing to bear in mind is that we have been talking about time designations. But going hand in hand with the time designations are rock designations. There is no general designation for rocks associated with eras, but rocks which formed during periods of time are known as systems. Thus, timewise, the Cambrian is known as a period, but the rocks which formed during this period are known as the Cambrian system of rocks. It is "the Permian period of time," but "the Permian system of rocks." The divisions of the time span included in a system are epochs for time, but series for rocks. The names given to the periods and the rocks formed during the periods are used on a worldwide basis.

But epochs of time, and series of rocks, ordinarily are named on a continental basis. They commonly are given geographic names, after the areas where the series of rocks are found. Thus, in North America, in the Silurian period, three series of rocks have been designated—Medinan, Niagaran, and Cayu-

Fossils are excavated slowly, with the greatest care.

gan—with the epochs taking the same designations. As a matter of ordinary practice, however, when there are three series of rocks, they are not always *called* by their geographic names, but are referred to merely as Lower Silurian, Middle Silurian, and Upper Silurian (or Upper Cambrian or Lower Ordovician, as the case may be). Similarly the time designation, rather than adhering to the geographic name, would be Early, Middle and Late (Early Silurian corresponding in time to the Lower Silurian in rocks).

Rocks of a series may be further subdivided into stages, with the corresponding time designations subdivided into ages.

And while all the above divisions and subdivisions hold true and are of use, it has come about that rocks are usually spoken of as lithographic units. That is, they are designated by formations which can be distinguished by sight. These for-

mations are tagged with geographic names. Thus we have the Dakota sandstone, the St. Louis limestone, the Middlesex shale. If a formation consists of more than one kind of stone, interbedded, no lithographic designation is made, but the formation is simply spoken of as the Morrison formation or the Supai formation or some other formation. In some instances, if it makes sense to do so, two or more formations which share some lithographic peculiarity may be included in a group. The Glen Canyon group of sandstones on the Colorado plateau includes several sandstone formations.

As more and more knowledge is gained, the geological time scale of the past is undergoing continual revision. The following scale, which at the moment is most generally accepted, was worked out in 1961 by J. Lawrence Kulp of Columbia University:

ERA	PERIOD	EPOCH	START OF INTERVAL *(in millions of years ago)*
Cenozoic		Pleistocene	1
		Pliocene	13
		Miocene	25
		Oligocene	36
		Eocene	58
		Paleocene	63
Mesozoic	Cretaceous		135
	Jurassic		181
	Triassic		230
Paleozoic	Permian		280
	Pennsylvanian		310 *(hazy)*
	Mississippian		345
	Devonian		405
	Silurian		425
	Ordovician		500
	Cambrian		600 *(hazy)*

And stretching downward from the Cambrian is the Precambrian, a great dark gulf of time of which not too much is known.

Which is not to be taken to mean that, knowing little about the Precambrian, we do know everything there is to know about the rest of the time periods which we have designated. We do know an astonishing lot about them, but there are a number of blank spots, many places where the record is far from complete and, perhaps, even a great many things and events about which at the moment we have no inkling.

The division lines between the eras are marked by certain profound changes concerned with crisis points in the earth's history. The Paleozoic begins with a period when certain conditions, not yet wholly determined, made possible the development of a number of fossil remains of early life. It may have marked the end of a long period of erosion which had wiped away most previous evidence of even earlier life. The Paleozoic ends with a time of deep crisis which made extinct a great deal of the life which during the Paleozoic had enjoyed a climate of eternal summer. The Mesozoic saw the rise of the reptiles, including the great dinosaurs, and when it ended almost the entire tribe of reptiles which had ruled the earth for more than 100 million years also came to an end. The Cenozoic saw the rise of the mammals. What great crisis, some millions of years hence, may bring an end to the Cenozoic, we have no way of knowing.

The eras are divided by what are known as geological revolutions, times of outstanding change in the character of the earth. The periods are divided by times of somewhat lesser changes, known as disturbances. Thus the Paleozoic era is divided from the Mesozoic era by the Appalachian revolution, while the Triassic, the first period in the Mesozoic, is divided from the following period, the Jurassic, by the Palisade disturbance.

Over the years numerous changes have been made in the geological time scale. Names have been changed and periods have been redivided and the time value has changed from decade to decade, the time span usually becoming longer with each change that was made.

Today we designate two American periods, the Mississippian and the Pennsylvanian toward the end of the Paleozoic era. In Europe, there is only one, the Carboniferous. In the early days the Silurian system was said to follow the Cambrian and it was not until 1879, following much bitter debate on the proper division of the two periods, that a new period, the Ordovician, was introduced between the Cambrian and the Silurian.

While the beginning of the Cambrian is generally agreed to date back to some 600 million years ago, there is some feeling that this date may range too far back into time. And while the beginning of the Pleistocene dates back traditionally to about a million years ago, cores taken from the floor of the Atlantic Ocean seem to indicate that more properly the Pleistocene may be said to have begun a million and a half years ago.

Hope for arriving at more absolute dates for all the time divisions lies in the system of radioactive analysis which has been worked out for dating rocks. Many rocks carry within their structure a timetable which can be read—not by just anyone, of course, but by technicians who know how. Within the next few decades, such experts are sure to have more to tell us about the history of the earth.

Radioactive dating is based on the principle that the isotopes of certain elements decay radioactively. An isotope, essentially, is a variant from the basic element. The chemical composition remains the same, but the atom of an isotope varies in atomic weight. The number of electrons that go to make up the atom remains the same, but the number of neutrons in the

nucleus varies, thus changing the atom's mass or atomic weight.

There are several different methods of radioactive dating. Methods used in the dating of rock are the potassium-argon method, the rubidium-strontium method, and the uranium-lead method. Another dating technique, the radiocarbon method, is of little value in learning the ages of rocks, but it has proved invaluable in the dating of material found by archaeologists. Theoretically, it is valid back to not more than 50,000 years. As a matter of practical application, 30,000 years is about the limit of its effective range.

Radiocarbon dating is based upon the decay of an isotope of carbon—carbon-14. Normal carbon has an atomic weight of 12. Carbon-12 is not radioactive. The carbon atom which has the atomic weight of 14, is.

Carbon-14 has a half-life of 5,700 years. That is, in 5,700 years, half of any given amount of carbon-14 will have vanished as a result of radioactivity. In another 5,700 years, half of the remaining amount will be gone, and only a quarter of the original amount will be left. All of it is gone by 70,000 years, but long before that point is reached the amount remaining is too faint to measure.

Carbon-14 is created in the upper atmosphere by the bombardment of high-speed particles coming in from space. For the purpose of measurement, it is assumed that the concentration of carbon-14 in the atmosphere is stable—that it is the same today as it was thousands of years ago.

Radiocarbon (carbon-14) enters the tissues of plants as they absorb carbon dioxide during the process of photosynthesis. Animals eat the plants and absorb the radiocarbon from the plant tissues. Other animals eat the animals that have eaten the plants, and they in turn absorb the radiocarbon.

Thus, in everything alive there is a stable amount of radiocarbon, and that amount of radiocarbon remains stable throughout the life of the organic being, whether plant or animal.

But as soon as the plant or animal dies, it quits absorbing carbon-14 and the radiocarbon in its tissues and bones then begins to disintegrate.

By analysis of a bone which once was a part of an animal, or a piece of charcoal which once was a part of a tree, or a grass mat which at one time was braided from once-living grasses, the amount of remaining radiocarbon can be determined. Knowing the rate at which radiocarbon disintegrates, it is possible, within certain margins of error, to determine the ages of the bone, the charcoal, or the grass mat. It doesn't have to be these three things. Anything that was once alive will do.

Thus it is possible to learn the age of once-living things which ceased to exist comparatively recently—not longer than 50,000 years ago.

But when one gets into the dating of rocks where millions, and in many cases, billions, of years are involved, a longer yardstick is needed.

Several such yardsticks exist. A number of naturally-occurring radioactive elements with long half-lives are found in rock. By measuring these, the age of the rock can be determined.

It is not an easy task. The process is long and laborious and great care must be taken. But there is no doubt about the accuracy of dating—always considering, of course, a margin of uncertainty which can be held within narrow limits.

In employing the potassium-argon, the rubidium-strontium, or the uranium-lead methods, a comparison is made of the amount of the original radioactive element and the amount of its daughter element in the rock. The more of the daughter element there is, the older the rock.

By daughter element, this is meant: In potassium-40, the radioactive isotope of potassium, the potassium decays to argon-40. Argon-40 is the daughter element of potassium-40. The decay of the one element to another is accompanied by

the emission of a gamma ray, which accounts for the radioactivity.

The measurement of potassium-40, as against argon-40, determines the age of the rock. The more argon-40 there is, in comparison with potassium-40, the older the rock.

Another method is the measurement of rubidium-87 as against its daughter element, strontium-87.

Ordinarily, in measuring any rock, both the potassium-argon and the rubidium-strontium measurements are made and the results are checked against one another.

A third method, somewhat more complicated, is the uranium-lead method, in which three radioactive isotopes of uranium are measured against their daughter elements. Uranium-238 decays to lead-206 with a half-life of four and a half billion years. Uranium-235 decays to lead-207 with a half-life of 710 million years. Thorium-232 decays to lead-208 with a half-life of 13 billion, 900 million years.

The half-life involved in rubidium-strontium is 47 billion years. In potassium-argon the half-life is one billion, 300 million years.

The uranium-lead method, by giving three independent measurements, provides a much better check on rock ages than comparisons of the results from the other two methods.

Should the three measurements in uranium-lead check out with one another, the age as shown is regarded as valid. Should they also check out with both potassium-argon and rubidium-strontium measurements, there can be no doubt about the age of the rock.

The potassium-argon method is interesting because potassium-40 has a double-barreled method of decay. Not only does potassium-40 decay to argon-40; it also decays to calcium-40, in this case with the emission of a beta particle.

About 90 per cent of the potassium-40 eventually decays to calcium-40, while 10 per cent decays to argon-40. Thus,

as a decay product, calcium-40 is nine times more prevalent than argon-40.

In dating rocks, however, only the argon-40 is considered. This is because there is too much calcium-40 in the ground, making it difficult to extract uncontaminated calcium-40 from a rock. In other words, the rock may have been contaminated by the calcium-40 which exists in the ground, which would result in too high a reading.

While there is a lot of argon-40 in the atmosphere (relatively, that is), it is possible to get argon-40 out of rock with practically no contamination. Argon-40 is fairly easy to extract from rock and since it is a rare, inert gas (a gas that refuses to combine with anything else) it is easily detected. The one uncertainty involved is in determining how much of the argon-40 that was in the rock originally may have seeped out of the rock into the atmosphere. For this reason, the porosity of the rock becomes a factor in determining age when this method of measurement is used.

In the atmosphere about three tenths of one per cent of the argon present is argon-36 and about six one-hundredths of one per cent is argon-38. The rest is argon-40. Argon-40 is by far too abundant in the atmosphere in relation to the other two isotopic forms of argon. It is believed that this is the result of the slow seepage, through the eons, of argon-40 from the earth's rock.

The amount of argon-40 extracted from a rock sample is fantastically small. A sample of a few grams of rock will yield no more than one one-hundred-thousandths of a standard cubic centimeter of argon-40. (A centimeter is roughly two-fifths of an inch. The "standard" means gas under a pressure of one atmosphere and at the freezing point of water. It is simply a standard set up for uniform measurement.)

The amount of argon-40 derived from the rock sample is measured by an instrument known as a mass spectrometer.

While it would be possible to measure the argon-40 alone, it is simpler to use what is known as a tracer technique. This means that a certain amount of pure argon-38 is added to the unknown amount of argon-40 in the spectrometer. The larger amount of argon makes it somewhat easier to get a reading. Once a reading is obtained, the known amount of argon-38 is subtracted from the total amount measured by the spectrometer and the remainder is known to be pure argon-40.

The process here outlined for the potassium-argon measure-

New technique for dating geological specimens is based on the fact that all minerals contain at least a few uranium atoms. These uranium atoms undergo natural fission at a known rate, splitting into two fragments of roughly equal size. As the fission fragments move apart in the mineral sample, they leave a trail of damage. Close-up shows burst of "fossil" tracks radiating from a speck of uranium in sample of mica. Age of specimen is determined by comparing ratio of "fossil" tracks to total number of uranium atoms in sample. New dating technique was developed by Drs. P. Buford Price and Robert M. Walker, physicists at the G. E. Research Laboratory.

ment is carried out in a similar fashion when either the rubidium-strontium or the uranium-lead method is used.

Radioactive dating is still in its infancy. There are still a few problems to be worked out. But it promises to give a more accurate time scale in geology than anyone, a few years ago, could have hoped. In the years to come it will give us a much better understanding of the history of the earth.

So far, the most impressive use of radioactive dating has dealt with the Precambrian.

Up until a few years ago the Precambrian had been mapped in what appeared to be a fairly logical order, the story of it reconstructed from a study of rock strata and other factors.

Nowhere has the Precambrian been studied more extensively than in northern Minnesota. The great Minnesota iron mines lie in largely Precambrian formations and a study of the rocks was a necessary part of the job of the mining engineer. The ancient rocks were studied in other parts of the world as well, but the most intensive study was in the iron mining areas.

But within the last decade the technique of radioactive dating has considerably revised this old, classical picture of the Precambrian. While the work has been done in various parts of the world, it is again in Minnesota, where a fairly detailed picture of the Precambrian had been built up, that the results are the most striking.

Plans were laid in 1955 for a co-operative program of radioactive dating of Minnesota's rocks by the Minnesota Geological Survey and the geology and physics departments of the University of Minnesota. Work was started in 1956 and the results were published in 1961.

The new picture of the Precambrian in Minnesota involves three orogenies (mountain-building periods). The Algoman orogeny occurred about 2.5 billion years ago; the Penokean occurred 1.7 billion years ago, and the Grenville took place about a billion years ago.

The new understanding of the Precambrian fairly well eliminates the old Laurentian orogeny, which had been given a place in the more classical sequence. If it can be considered in Minnesota at all, it is as no more than a forerunner of the Algoman orogeny.

Gone, too, is the old Killarney mountain-building period which was tentatively set up under the earlier interpretation of the Precambrian. The so-called Killarney granite found in the central part of Minnesota now appears to be Penokean in origin, and the Duluth Gabbro complex dates from the Grenville orogeny.

So what we have now, as a result of the radioactive findings, is this: During three periods, separated from one another by millions of years, three great mountain-building revolutions changed the geography of the primitive land in the Lake Superior region (there was, of course, no Lake Superior at the time and would not be for a couple of billion years). It is possible that mountains existed during all three periods of revolution, although in some instances the land may only have been lifted into high plateaus. But each time, when the mountain-building activity was finished, the forces of erosion took over and in each instance the heights were worn down.

There is evidence that the three orogenies which affected Minnesota were world-wide events, that the entire world at those times was in the throes of mountain-building and of great change.

It seems probable that the Algoman orogeny, which began some two and a half billion years ago, lasted for something like 200 million years. The mountains seem to have extended eastward from Minnesota into Quebec.

The Penokean orogeny, beginning some 600 million years after the end of the Algoman (by which time, of course, the Algoman mountains would have disappeared), may have lasted as short a time as 60 million years, or as long as 120 million.

Here the mountain-building activity was located somewhat south of the line along which the Algoman revolution had operated, but trended in the same direction.

Once the mountain-building had ended, the rocks which had been lifted were worn down by erosion and new rock strata were formed.

The Grenville, the last of the great Precambrian orogenies, took place a matter of 600 million years after the Penokean. In the years that followed, erosion once again reduced the rocks which had been thrust up during the orogeny, and once again new sedimentary rock was formed.

The Grenville may have produced less change than the other two orogenies. There is little folding of rock which can be attributed to the Grenville. What little there is can be correlated to folded Grenville formations in the eastern part of the United States, bearing out the belief that the orogenies may have been very extensive, and perhaps world-wide.

In the work that was done in Minnesota, the potassium-argon method was used to begin with. Later rubidium-strontium dating also was employed. Plans had been made to use the uranium-lead method, also, but this part of the program was not carried out.

The story, however, was not complete in Minnesota.

Dr. Samuel S. Goldich, who had headed the program, left the University of Minnesota to go to Washington, D. C., as chief of isotope geology with the United States Geological Survey. In that post he continued with some of the work which had been started in Minnesota. He decided to use the uranium-lead method to determine the age of the Morton gneisses, which are located in great outcroppings along the middle reaches of the Minnesota River.

Earlier in this book, it was pointed out that gneiss is a metamorphic rock, its characteristics changed by recrystallization under heat and pressure.

Dating by the potassium-argon method had shown that the

Morton gneisses were 2.5 billion years old. Other gneisses in the same general area have shown an age of 1.8 billion years.

This dating was a good and solid answer; there was nothing wrong with it. But atomic clocks are peculiar in one respect —they can be reset.

When a rock is metamorphosed, changes are made in its crystalline structure. The recrystallization resets the atomic clock. Thus, the clocks in the rock may have been clicking away for millions of years up to the point at which a shift in the surface structure resulted in the rock being metamorphosed.

With the metamorphosis, the atomic clocks are reset. The clocks then will show only the date from the time of the metamorphic happening, and the rock consequently will date to a younger age than is actually the case.

But within many rocks is a mineral known as zircon, which is resistant to change. Thus, while the rest of the minerals which make up the rock may be recrystallized, zircon is apt to retain its original crystals.

This is what had happened in the Morton gneisses. The rock had been metamorphosed some 2.5 billion years ago, and that was the age it had shown when it was first dated. But an analysis of the zircons, the last resistant residuals of the original rock from which the gneiss was formed, showed an age of 3.3 billion years.

Thus we know that the original rock was formed about 3.3 billion years ago, and that some 800 million years after it was formed it was involved in a geological upheaval which recrystallized it and reset its atomic clocks.

The Morton gneisses stand today as the oldest known rock in the Western Hemisphere. The oldest known rocks in the world, dated at 3.4 billion years, have been found in South Africa and in the northwestern corner of the Soviet Union.

4. THE FOSSIL RECORD

So FAR we have considered the forces which formed the earth as we know it (and which, even now, are slowly changing it) and the rocks which can tell us, if we can read them correctly, the story of their formation.

There is one other major factor which must be taken into account in any attempt to arrive at an understanding of past ages. That factor is life.

No man knows how life came upon the earth.

Some day, perhaps, we may have the answer. At the moment there are several clues which point toward that answer.

The most probable answer seems to be that life came into being as the result of chemical combinations during that early period when the earth was a seething laboratory in which almost anything could happen.

In other words, life evolved out of non-living elements.

When the first great rains had fallen on the earth, the way may have been cleared for the formation of life. There was water on the surface of the earth, and the greater part of the water vapor which had been held captive in the clouds had been cleared from the atmosphere.

The atmosphere probably consisted largely of methane, ammonia, hydrogen, and nitrogen. There was oxygen, of course —it is a component of water—but it was in combination. Because there was no free oxygen, the ozone layer, which today absorbs most of the ultra-violet rays from the sun, had not formed in the atmosphere. Ultra-violet radiation came lashing in from space with nothing to impede it.

Ultra-violet is that ray which can give us a deep sunburn if we are not careful. If it were not shielded out by the ozone layer, life would be impossible on earth. Too much ultra-violet is deadly to living things. But ultra-violet radiation, because of the great amount of energy it packs, may very well have been one of the factors which brought forth the first life upon the earth.

As earth's brand new seas lay sparkling in the light of the primitive sun, new clouds formed and lightning lanced across the sky and new rains fell. Volcanism perhaps was more intense than we can well imagine. Geysers and hot springs spouted and hundreds of great volcanoes must have exploded each century, hurling masses of fine dust high into the sky.

It is possible that this dust played a part in the creation of life. A tiny grain of dust may have picked up molecules of methane, ammonia, and hydrogen and microscopic drops of water and carried them high into the atmosphere. There the ultra-violet radiation came raging in, perhaps even stronger than it is today, for at that time the sun was as new and as primitive and as savage as the earth.

If energy were needed to create the first building blocks of life, there, in the ultra-violet, was energy in plenty. And there were the raw materials, a witches' brew in which chemical reactions were taking place continually.

Or it may have been the great bolts of lightning which supplied the energy. Or it may have happened in some other way. No one knows.

Amino acids, the basic building blocks of the protein molecule, may have been one of the first life products. Amino acids are compounds of carbon, hydrogen, oxygen and nitrogen, and all of these were present.

If the fierce energy of the ultra-violet rays stirred the elements into combination—the same energy the next instant might ruthlessly destroy them. But perhaps a tiny fraction of them fell into the clouds, which may have offered them some protection. Some of them may have drifted from the clouds, or been carried down by rain, into protective water. Or they may have been formed, to start with, only a few inches or a few feet above the surface of a body of water, and thus had the better chance to reach its protection.

Somehow, by some process of chemical combination, by some application of energy, amino acids and other components of life came into being. Century after century they may have rained down into the water, until in time the water may have been loaded with amino acids.

The amino acids are the building blocks of protein and the proteins are the building blocks of life. Every living thing has its share of proteins. The virus, that strange structure which hovers on the borderline between life and non-life, is a protein which is hunting for a home. Without a home, it is non-living, once it finds a home it becomes life.

So that if we had amino acids, we then would have proteins, and if we had proteins we would be well along the road to life.

Given trillions upon trillions of possibilities for chemical combinations, given a few million years for it all to happen, the components of life would have appeared. And once that had been accomplished, once the bricks and the stones and the lumber for the building of life were present, then all that would have been required were a few more million years for life to actually appear.

Life could not evolve in this manner today. Oxygen would

attack the chemical combinations of the building blocks of life. Those that weren't destroyed by oxygen, would be destroyed by bacteria. But in the day when life was formed, there was no free oxygen and there were no bacteria—simply because bacteria is life and life had not become a fact as yet.

Amino acids have been created in the laboratories in much the manner described above. The classic example is the experiment performed by Dr. Stanley L. Miller in 1954, when he was working on his doctor of philosophy degree at the University of Chicago.

Duplicating what undoubtedly were the primitive conditions on earth, Miller put ammonia, methane, water vapor and hydrogen into a large sterilized container, heated the mixture to a temperature which must have obtained in those ancient days, and ran an electric spark through the mixture.

He let the mixture set for a week and then analyzed the results. He found that 35 different amino acids had been created.

Further experiments conducted since then have tended to bear out the results of the Miller experiment.

So it would seem apparent that while this may not have been exactly the way life originated on the earth, it could have happened in this way.

But, finally, somehow, perhaps in the manner described above, perhaps in some other manner we have yet to discover, the components of life would have been present on the earth. And once the components were there in plenty, life would have been achieved. It would necessarily have been the lowest common denominator of life, the simplest form that life could take and still remain alive. It was a blob, a speck—a fragile thing in an extremely hostile world.

Today we have at least one and a quarter million distinct species of plants and animals upon the earth. There are, for example, more than 500 different kinds of fleas alone. All of these more than a million and a quarter different kinds of

life must necessarily have had their common roots back in those tiny original organisms which may have been created almost five billion years ago. Everything that lives upon the earth today sprang from those primordial ancestors, from those terribly fragile things which came into being in that nightmare world of the first beginning.

And how, one may ask, did this all come about? What is the path from the simplest living thing that could exist five billion years ago to the millions of complex things that live today?

The answer lies in a process that is called evolution.

The theory of evolution says that the primordial life about which we have been talking evolved or developed (or slowly changed) through long millennia into all the later forms of life, both those which still are with us and those many others which have disappeared from earth.

Basically, we might say that the process of evolution is based on adaptation, and that adaptation occurs through natural selection.

The theory of evolution was first set forth by Charles Darwin, son of an English doctor and grandson of a famous scientist. Darwin began the observations which finally resulted in the theory when he embarked in 1831 on a five-year cruise around the world on a British sailing ship, H.M.S. *Beagle*. It was not until 1859, however, that he finally published his conclusions as a book entitled *On the Origin of Species by Means of Natural Selection, or The Preservation of Favoured Races in the Struggle for Life*. When we speak of the book today we simply call it "The Origin of Species."

He observed that no two plants or animals are ever reproduced exactly alike. There are always some slight differences. The differences would usually be small and insignificant.

Darwin believed that among both plants and animals there was a process going on which could be called the survival of the fittest. That is, those which are better adapted to their

environment are the ones which are the most likely to survive.

Those animals or plants which are best fitted to survive flourish in their surroundings. They have young, and the young which once again survive are those which have inherited from their parents those characteristics which best fit them to their environment or which have additional favorable variations of their own.

Thus the animals or plants with the best characteristics to fit their environment survive, while those with poor characteristics or those which lack certain characteristics die out.

This is where the natural selection comes in—the weeding out of the unfit. Nature is picking and choosing to select those forms of life which can turn their surroundings to their best advantage, or which have the most workable defense against certain conditions in their surroundings.

At times an animal or plant may become so well adapted to its environment that when the environment changes, it cannot change with it. It is frozen to one environment and cannot tolerate any deviation from it. This may be what happened to the great reptiles of some millions of years ago. They may not have been able to survive a change in their environment.

On the other hand, however, when an environment changes, an animal or plant with hitherto unfavorable characteristics might now become the one best fitted to survive, its unfavorable characteristics becoming favorable under the new conditions.

While it probably happens less often, another means of evolution is by mutation.

Occasionally an animal may be born with a characteristic strikingly different from those of any other animals of its species. More often than not, the mutation is unfavorable. It ordinarily makes the animal less adaptive to its environment, weighing against its prospect of survival. Such a mutant probably will die early and the mutational characteristics will be cancelled out.

But it happens as well, although not nearly so often, that a mutation is favorable. The animal which is thus mutated has a better chance of survival and may pass the mutational characteristic along to at least some of its young. They, in turn, will pass it on to some of their young and those animals, better fitted to survive, will become solidly established as an evolutionary form.

But evolutionary changes, in any event, are slow. They take a long time to work themselves out. Once again, in the long history of the earth, there has been time in plenty for life to develop in many different ways.

Evolution, however, can lead to a dead-end. An animal which becomes highly specialized to take advantage of its environment usually becomes extinct when an important aspect of the environment changes. He has gone too far; there is no way to go back.

It may be that man is as successful as he is today because he is an unspecialized creature. He can manage, in one way or another, to adapt to a wide variety of environments.

A particular fish developed the ability to breathe through nostrils as well as through its gills. This was evolution. Later, when the pond in which it lived shrank and became stagnant, it could rise to the surface of the pond and breathe. This gave it a better chance to survive than its gill-breathing fellows, which were suffocated in the stagnant, oxygen-poor water.

Later on this fish, or rather, its far descendant, developed stubby legs where its fins had been and was able to walk upon the land, enabling it to quit the stagnant pond and make its way to one where the water was less stagnant. This was an end-product of evolution. In time, the fish-that-walked-on-land became an amphibian, an amphibian became a reptile, a reptile gave rise to mammals. This all was evolution, made up of many tiny evolutionary advances—a long and painfully slow process.

The horse developed from an animal the size of a fox;

the elephant from an animal the size of a hog. The development was not in size alone. The animal the size of a fox did not look particularly like a horse, nor did the animal the size of a hog look particularly like an elephant. The process of evolution was arrived at most deliberately and incorporated many changes, not just one change.

Everything that exists upon the earth today is the product of evolution. Everything that lives today is the end result of those characteristics which enabled its remotest ancestors to survive.

As in rock, so in life—nothing is meaningless. Nothing is a product of blind chance. There is a reason for every form of life. But for those reasons we must search far back. Each reason, if it can be found at all, has a long and, at times, a tortuous history.

One may wonder how all of this is known.

A good part of the answers lie in fossils.

Fossils are the remains of things which at one time were living or which were closely associated with living things. A fossil need not be a piece of bone; it can as well be a footprint

Nest of dinosaur eggs was found in the Gobi Desert.

made by some form of life that died millions of years ago. A fossil is any evidence still preserved which can help us understand the life of past ages.

During the ages life developed along evolutionary lines. It progressed from the simple to the complex, from the general to the specialized. One form of life slowly changed into a different form of life or into many different, but related, forms of life. From one common ancestor, through the ages, arose many different forms. Adaptation to living conditions through the slow changes in the bodies and the living habits of a certain kind of life resulted time after time in the development of a significantly different form of life.

By a study of these developments, as demonstrated in the fossil remains of these life forms, it is possible in many instances to trace the developments, to say which form came first and to get an idea of the chronology of the various forms as they developed. In this way, we have gained a fairly clear picture of the progression of life in general through the several geologic periods. And the knowledge of the evolutionary progress of life supplies a yardstick with which to measure time.

By study and comparison of fossils found in different rock strata, the time sequence of the rocks can be determined and can be related to other rock strata in other places throughout the world.

Like the rock strata, the fossils in the rocks can be compared to the pages of a book. Scientists know how and when a great number of the life forms evolved and thus are able to say with some certainty that a certain layer of rock is older than another because the fossils in it date from an older time sequence.

In this respect, certain fossils are known as guide (or index) fossils. The mere finding of a guide fossil is sufficient evidence to date a rock to a certain time bracket. To be valuable as this kind of guide, a fossil must represent an animal which

lived over a comparatively short length of time, which occurred over most, if not all, the world, and which existed in abundance.

Oleneullus, a trilobite with a sharp, pointed tail, lived only during the Early Cambrian, dying out at its end. Thus *Oleneullus* is a guide fossil for the Lower Cambrian. Any rock that carries a fossil of this particular trilobite was formed during the Early Cambrian. Several types of large-tailed trilobites first appeared at the beginning of the Middle Cambrian and died out at its close. These are the guide fossils for the Middle Cambrian. A prong-tailed trilobite, *Crepicephalus,* is the guide fossil for the Upper Cambrian.

Not only can such a guide fossil aid in the identification of rock as belonging to a certain segment of geologic time, but it can be used to correlate rocks in many different parts of the world. If a rock in New Jersey carries the same guide fossil as a rock in Mississippi, then it is safe to assume that the two rocks were formed at the same time. That "same" time may be a large segment of time, several million years, perhaps, and the fossil which is found in one rock may have lived hundreds of thousands of years later or earlier than the fossil found in the other rock. But so far as geology is concerned a million years is a mere sliver of time as weighed against the hundreds of millions of years which are represented in a geological study of the earth.

The correlation might not be New Jersey or Mississippi; it might be Wisconsin and South Africa, Alaska and Wales. No matter how widely separated the rock strata may be, they can be tied to the same geologic unit of time if they contain the same guide fossils.

The identification and correlation of rock strata by guide fossils does not work in the Precambrian, for the reason that few fossils are found in the Precambrian. Some have been found, but not enough of them to show any evolutionary trend upon which age comparison can be made. For this reason,

radioactive dating is especially significant in connection with the Precambrian.

But the method does work with the beginning of the Paleozoic era, for in the Cambrian, the first period in the era, fossils become plentiful.

When we think of a fossil, we generally think of a certain part of an animal, usually a bone, which has been turned to stone. And this is a fossil, certainly, but there are many different kinds of fossils. Even a fist axe or a stone scraper used by a primitive man thousands of years ago can be considered a fossil under certain conditions.

The most spectacular fossils are the actual bodies of life forms which have been preserved without any sort of petrifaction or mineralization.

Bodies of the woolly mammoth and the woolly rhinoceros have been found in the frozen muck of the Siberian and the Alaskan tundras. In these cases the actual tissues of the bodies have been preserved, the low temperature of the permanently frozen ground (the so-called permafrost) having inhibited all bacterial action and decay.

In 1930, the preserved body of a woolly rhinoceros was found in an oil seep in Poland, the waxy hydrocarbons of the oil having preserved the body against decay. In the southwestern United States and in South America, the skeletons of ground sloths have been found in dry caves with parts of the dessicated hide and hair and some of the tendons preserved by the aridity of the atmosphere.

These animals, the sloth, the mammoth and the rhinoceros, are not ancient animals, of course. They lived perhaps no longer than ten thousand years ago, if that.

But some really ancient things are preserved virtually intact. Logs have been found, embedded in Cretaceous clays and Eocene lignites, so well preserved that they still retain their woody structure and will burn readily. The Cretaceous period came

to an end more than 60 million years ago and the Eocene period 36 million years ago.

Finds such as these are rare, however. More generally fossils take that form in which we habitually think of them, the organic structure more or less preserved in stone.

Petrifaction is the process by which the original structure of a once-living thing (a bone, a tree, a shell, an insect or something else) is replaced by stone. Petrifaction can take place in two ways. Permineralization is the process by which mineral matter, carried in solution by water, fills in all the open spaces in the bone, or whatever it may be, without altering the original structure. Replacement is the process by which the original matter is dissolved and carried away and is replaced by mineral matter. In many instances of replacement, the change is so slow and so delicate that even the smallest details of structure are faithfully retained by the mineralization. In some other cases, no detail is retained by the mineralization and only the external form of the fossil is retained. Such a fossil is known as a pseudomorph.

Beautiful carbon copies of leaves and other plant material are provided by another method of fossilization. This occurs when the volatile elements in the organic material are distilled away and a residue of carbon is left to record the form of the object. In rare instances this also occurs with animal tissue.

Under certain circumstances, shells or other organic objects embedded in rock may later be dissolved, leaving an open space in which an imprint of their form is molded. This is called a natural mold. But let us say that after the original organic matter has been dissolved, water than brings in a mineral which fills the natural mold. Now we have what is known as a natural cast.

The most remarkable natural molds are of insects and spiders trapped in amber. Amber is the dried and hardened sap of evergreen trees. It is found principally in the Baltic region in northern Europe. Apparently, the insects were trapped and

Imprints of fossil leaves (left) are preserved in shale. Natural molds (above) show form of dissolved fossils.

enclosed by the exuding sap, which finally hardened before they could escape. In time the insects' bodies dried and withered away, but casts of their shapes remained within the amber.

Another type of fossils is the imprint. Thin objects, such as leaves, leave their imprint in the mud upon which they fall. In time the organic substance decays away, but the imprint still is there. In time the mud turns to stone, and under ideal conditions it retains the imprints of the fallen leaves.

Footprints left in mud, which later turns to stone, also are fossils. Many dinosaur tracks, made by creatures now dead for millions of years, have been found. A scientist can learn much from such footprints. He can tell whether the creature went on four legs or two, whether it was fast or slow in its movements, whether it crawled, hopped, walked or ran.

Another important fossil is the coprolite. A coprolite is fossilized excrement, and is valuable because it furnishes clues

Modern leaf (above) was recently encased in limestone. Ancient tracks were preserved in the same way.

to what the ancient animal ate. At times it contains undigested hard parts of the plants or animals which had been eaten.

Special conditions are necessary for fossilization. Only a very small percentage of all the things which lived through the ages ever became fossilized. Ordinarily they simply decayed or, since our world is a very hungry world, were eaten.

That so many fossils are present attests to the great variety and the almost inconceivable number of lives which have been spent upon the earth. It also emphasizes the vast amount of time involved.

Animals or plants with hard parts, such as chitin covering, shells, bones, and wood had (and still have) the best chance of becoming fossils. Soft-bodied creatures such as worms and jellyfish have left us few of their remains. Worms, however, often do leave a record of their existence—their wriggly tracks which are preserved in stone.

Quick burial is the most important circumstance favorable to fossilization. Left exposed after it died, a creature would either decay or be eaten. Under water or in moist sediments, however, weathering is prevented, bacterial action resulting in decay is reduced, and scavengers are foiled.

Quick burial may be accomplished in many ways. Animals could be trapped by floods and buried under sand and mud. They could be trapped in bogs, quicksand, or tar pools, sinking quickly out of the reach of scavengers. The La Brea asphalt pits in what is now the city of Los Angeles trapped and held through the ages a great grab bag of ancient animals. There are other such places throughout the world.

Other animals could have been buried beneath the fall of volcanic ash. At Grand Coulee, Washington, thousands of years ago, a two-horned rhinoceros was engulfed in a lava flow. The animal may have been dead before it was engulfed. The lava cooled so rapidly that the structure of the animal was not destroyed by the heat. An imprint of the rhinoceros was left in the lava, to be discovered many years later.

The remains of plants and animals may be covered by shifting sands. This only rarely results in fossilization, because sand is not a good agent of preservation. But occasionally fossilization does take place in dry sand. The famous dinosaur eggs of the Gobi Desert were preserved in this manner.

It is in sea bottoms that most fossilization occurs. There the marine life sinks to the bottom as it dies. Much of it is scavenged, but some of it is buried in the mud, which in time may turn to stone and preserve the record of buried forms.

And while we think of fossils as being something associated with great age, we must not lose sight of the fact that the process of fossilization still goes on. It is not too wild a thought to say that if men (and paleontologists) are still around a million years from now, they may unearth fossils of things which are alive as these words are being read.

5. THE PRECAMBRIAN

Dark Age of Geology

EARTH'S HISTORY, insofar as we can read it, began about 3.4 billion years ago. Readings of that age have been obtained by radioactive dating of rocks in the Johannesburg area of South Africa and in Karelia, the northwestern province of Russia. This does not mean that tomorrow or next year older rocks will not be found. There may be many rocks which can claim a greater age. They may be buried under younger rock, where we can never reach them. Or they may lie in some obscure outcropping against that day when someone will come along and discover their great age.

Somewhere, certainly, there must still exist some portion of the original crust of the earth. But to date no one has found it. Discovery of some portion of the primeval crust would be of enormous interest, for a study of it might settle, once and for all, the controversy over whether, at any time, the primitive earth was molten.

But at the moment the ancient rocks of South Africa and Russia are the first landmarks of the Precambrian era. (The Cambrian is that period where we can stand on fairly certain ground so far as the geological time sequence is concerned.)

Deeply eroded chasms of Grand Canyon, Colorado, offer rare opportunity to study ancient Precambrian rocks.

The Precambrian era is a sort of Dark Age in which there are few guideposts. Radioactive dating, and other newly-developed techniques, however, now are providing us a few benchmarks in this shadowy era, and as time goes on we will gain a far better understanding of it.

Extending from 3.4 billion years ago up to the beginning of the Paleozoic era, 600 million years ago, the Precambrian era embraces four fifths of the geological record of the earth and probably more than half of the earth's actual age.

The Precambrian era covers a vast amount of time; plenty of time for many things to happen. We are fairly certain that

many things did happen. We know of some of them, but not nearly all.

As we have seen, studies at the University of Minnesota have shown that in the area of Lake Superior during the Precambrian, three mountain-building orogenies took place and three times erosion wore away the mountains. In Sweden, which also is a land of Precambrian rock, J. J. Sederholm, the distinguished Finnish geologist, found that four great layers of sediment had been deposited during the Precambrian, representing cycles of sedimentation, separated by periods of mountain-building.

In the Grand Canyon of the Colorado, where the deep walls of the chasm have laid bare a history book of rocks, another story can be traced, even more detailed, of this age.

The Grand Canyon story of the Precambrian shows that first there was a great period of mountain-building, followed by a long period of erosion, which wore the mountains down to a level plain. A shallow sea then spread across the plain-that-once-had-been-a-mountain. Indications are that during the time this sea lay over the land, there may have been a long period of arid conditions, reducing much of the surrounding country to a desert. But in time rains fell again and the record of the canyon walls shows that rivers flowing into the shallow sea brought in heavy loads of sand, probably from the sand dunes of the desert. Finally the land stirred once again, and the rock strata which had been laid down during the long ages of the ancient sea were twisted upward into another mountain range. Before the middle of the Cambrian period this mountain, in its turn, had been eroded to a level plain.

Geologists presume that Precambrian rocks are worldwide in extent, but on four fifths of the earth's surface they are covered by younger rock. If one were to look for them, he would seek them in a few deep chasms, such as the Grand Canyon, in the cores of mountain ranges where the ancient

rocks had been uplifted and the overlying rock later worn away by erosive forces, or in the so-called shields.

The greatest extent of Precambrian rocks in North America lies within the Canadian Shield, which covers just slightly more than two million square miles in the northeastern part of the continent, surrounding Hudson's Bay. Most of the shield lies in Canada, but about 93,000 square miles of it extends into the United States, west and south of Lake Superior and in the Adirondacks in northern New York.

There are a number of such shields through the world. They are stable areas which since Precambrian times have not changed appreciably. Through much of geologic time they have stood in place while the lands beyond their borders changed time and time again. They are called shields because the chief areas of these ancient rocks are gently arched, like the surface of a medieval shield.

Other than the Canadian Shield, there are the Guiana Shield in northeastern South America, the Amazonian Shield extending along the east coast of South America, the Australian Shield in western Australia, the Indian Shield in the southern half of India, the Ethiopian Shield extending from Saudi Arabia down the eastern spine of Africa, the Baltic Shield in Scandinavia, and the Angara Shield in Siberia.

There is no way, of course, to know the shape of the continents during the Precambrian. Over the course of almost three billion years the face of the earth must have changed many, many times.

We know about the mountains and the shallow sea which once covered the Grand Canyon area. We know, too, that at one time or another during the era four mountain ranges lay in Canada, one of them extending southward into what is now the United States. And we know that the mountain range which extended into the United States was uplifted and worn away three times. One of the four Canadian ranges lay southeast

Shading indicates exposure of continental shields.

of the present Great Slave Lake, another along what is now the eastern shore of Hudson's Bay, the third in Labrador, and the fourth along the southern edge of Canada and south into the United States. It extended from the St. Lawrence Gulf into Minnesota, covering the upper edge of the present Great Lakes region.

We know these few things; we know but little more.

During all of the Precambrian era and well into the next era, the Paleozoic, the earth's surface was an empty place. There were only rocks and water. There were no trees, no grass, no flowers. It would be millions piled upon millions of years before there would be such things as grass or trees or flowers. The wind blew and clouds moved across the sky, rain fell and waves crashed upon the rocky beaches, but there was no other movement. The land held nothing that could move of its own free will.

Life existed in the sea, as long again, at least, as two billion

years, and perhaps much earlier than that. Life, indeed, must have been present upon the earth for the entire span of the Precambrian. But it would have been a tiny and an unobtrusive life. Much, if not all, of it would have been microscopic. For millions of years it may have lived and died and left little trace behind it.

Life in those days was a frail thing. But time was working for it. All it had was time and that stubborn persistence which is life's innate characteristic. Over the long ages it grew and developed, changing to better fit itself to exist in its environment. From such small beginnings, in ages yet to come, it would swarm, in almost unbelievable numbers and shapes and sizes, in all the corners of the earth.

Today we have evidence of Precambrian life, but so short a time as sixty years ago we had no such evidence.

And yet, even if today we still had no shred of evidence, we nevertheless could make a good case for life having existed in the Precambrian era. For, with the dawn of the Paleozoic era, life was well along its way. In the Cambrian period, there was life in plenty and of many kinds. With the single exception of the vertebrates, the back-boned animals, every phylum of creature which exists today is found in the fossils of the Cambrian period.

All of which, in itself, is a powerful argument that life must have existed in the Precambrian era, in great numbers, in many forms, and for a long, long time. Behind the known creatures of the Cambrian lay millions of years of evolution and development. That evolution must necessarily have taken place in the Precambrian.

For more than fifty years geologists hunted for Precambrian fossils. It was not until a few years ago that any significant number were found.

Prior to 1923 the most abundant Precambrian fossil indications were structures built of calcium carbonate, precipitated

by what must have been a kind of very primitive algae. Calcium carbonate is a chalky mineral which is the chief constituent of limestone. The algae apparently grew in mold-like colonies. Each colony, of course, would precipitate very little calcium carbonate in any one year or in any hundred years. But over the course of thousands of years it would build up a considerable structure, usually in the form of a reef.

Such tiny plants as these Precambrian algae still are common today, living in present-day oceans and lakes. What is more, there is evidence of their work in all geologic ages. They have been with us from the far beginning.

One of the most arresting evidences that can be seen of these reefs occurs in areas over which glaciers have passed, scouring away the surface of the rock. In some instances the ice will have cut away the summit of a number of small reefs, exposing them in cross-section, beautiful little circular patterns with deposit rings showing.

In addition to the reefs built by the calcareous algae, the early searchers found what apparently were worm tracks and burrows. The worms themselves were not found, only the traces they had left. From time to time other "fossils" were discovered, but the greater part of them were suspect and the search went on for undeniable Precambrian fossils.

Aside from the worm tracks and the calcareous reefs, there was some further evidence of Precambrian life—but evidence that was terribly hard to nail down. This was the carbon or the carbonaceous material found in the Soudan iron formation in Minnesota and in other Precambrian rocks in other areas. Most of these deposits appear in sedimentary rock, and where carbon appears in sedimentary rock there is little question that it is of organic origin, that at one time it was a part of a living thing. Following that rule, there seemed at least reasonable cause to consider the carbon in Precambrian rocks also as organic in origin. However, one couldn't be positive. For

it would be possible, under exactly the right conditions, for chemical reaction to break down calcium carbonate, freeing the carbon. Thus, while the existence of carbon could be argued as a reason for belief in Precambrian life, standing alone it could not be admitted as positive proof.

Then, in 1923, the first actual Precambrian fossil was discovered, positive evidence of a life form itself rather than of reefs or tracks left behind by living creatures. In that year, Dr. John W. Gruner, of the University of Minnesota, reported finding fossil algae in northern Minnesota rocks. In 1925 other finds of the same kind of algae in a different Minnesota area were reported by Gruner. The discovery created a stir at the time, but as the years went on and no other Precambrian fossils were found, there was a tendency to forget that the discovery ever had been made.

In 1947 the Australian geologist R. C. Spriggs, on a field trip to the Edicara Hills in South Australia, found several varieties of what appeared to be fossil jellyfish in a sandstone stratum which was at that time believed to belong to the Lower Cambrian—that is, the Early Cambrian, Lower because it belonged to the lowest stratum in the Cambrian sequence of rocks.

Other geologists, visiting the area, found further fossils, including some plant-like impressions that looked like algae. Two private collectors, Ben Flounders and Hans Micham, discovered fossils of segmented worms, a number of worm tracks, and impressions in the sandstone of two animals bearing no resemblance to any known creature, either fossil or living.

The South Australian Museum and the University of Adelaide undertook a joint investigation of the region. The work was carried forward by Dr. Martin F. Glaessner, of the University of Adelaide. A re-examination of the stratum involved showed that the sandstone in which the fossils had been found lay below the Cambrian stratum and that the fossils therefore belonged to the Late Precambrian.

The rock in which the fossils are found does not contain radioactive minerals suitable for dating, so there is no way of knowing how old the fossils are. The rock stratification in the area, however, is unbroken and can be followed with ease. The fossils lie in sandstone which is a good 500 feet below the first rocks which show undoubted Cambrian fossils.

To date, several hundreds of fossils have been found in this Precambrian sandstone. They include several kinds of jellyfish, soft corals, segmented worms with strong head shields, some other rather strange-looking worms, and the two unknown animals.

All of the animals represented in the fossil beds were soft-bodied and had no shells or other hard parts to aid in fossilization. Fossilization apparently came about when the creatures were stranded on mud flats bordering a body of water. A high tide or a shifting current then covered them with a layer of fine sand. The mud in time changed to a slate-like rock and the sand to quartzite. The bodies of the animals thus trapped, or the impressions made by their bodies, remained within the rocks as fossils.

Some of the fossils found in the Australian hills bear a close resemblance to two fossils discovered by German geologists prior to World War I in southwest Africa, and to a single fossil which was discovered only a few years ago in England. It is probable that the South African and the English fossils also belong to the Precambrian.

All of the Australian fossils represent animals which lived in water, some as free-moving forms, others perhaps affixed to the bottom of a shallow lake or sea.

For the first time, the Australian sandstone demonstrated that the Precambrian had not been as barren of life as the lack of any prior evidence might have made it seem.

Then, in 1953, Dr. Stanley Tyler, geologist at the University of Wisconsin, working during the summer as a consultant to

the Oliver Iron Mining Company in northern Minnesota, found his work finished with still a few days to run on his contract. He asked if there were anything else he could do. A company official recalled that some traces of iron had been found at a place called Schrieber Beach on the north shore of Lake Superior. He hastened to add that the indications had not been too promising.

"We have the time," said Tyler. "Let's go have a look."

He and the company official drove to the nearest approach to the location, then walked four miles through a tangle of Canadian bush.

The company official had been right. The iron indications were poor. But Tyler, with the habit of all geologists, chipped off a few pieces of rock and put them in his pocket. The samples, of a rock that is called Gunflint chert, were known to be ancient.

Later in the year a technician at the University of Wisconsin was engaged in making rock sections, sawing out extremely thin slabs of rock for study under a microscope. Tyler had been given a quota of twenty sections to be sawed, but the rocks he wanted did not quite fill out his quota. To fill it out, he threw in two of the specimens he had taken from Schrieber Beach.

When he put the sections from these rocks under his microscope, he saw the last thing he had ever dreamed of seeing.

Embedded in the rock were fossils of microscopic organisms that had been living when the world was young. They were not mere impressions, but fossilized three-dimensional life forms. They could be studied in cross-section and in detail. Their structure had been so delicately replaced by minerals that the most minute structure still retained its form.

Tyler showed what he had found to Dr. Elso S. Barghoorn, Harvard biologist. The two men then worked together in an attempt to learn the extent of the life found in the Gunflint

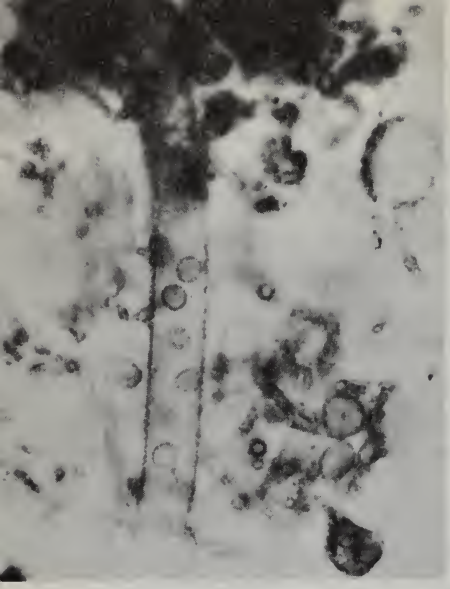
chert and to identify it. They examined more than a thousand rock sections taken from the chert, and the fossils continued to appear. What is most important is that the fossils are not isolated in one section of the chert. Gunflint chert from Kakebeka Falls in Ontario, near the Ontario-Minnesota border, also has been found to be fossil-bearing. The chert correlates with other strata of rock in Minnesota, Wisconsin and Upper Michigan—that is, these other rock formations are related in time and geological position to the Gunflint chert. This means that the fossils may exist in many places throughout the Lake Superior region.

In the spring of 1962, Dr. Patrick Hurley, of the Massachusetts Institute of Technology, dated the Gunflint chert by radioactive analysis. The reading came out to 1.9 billion years, with a possible error of 200 million years either way. Which means that the fossil creatures found within the rock lived almost, or perhaps a little more than, two billion years ago.

In speaking of the fossils, both Tyler and Barghoorn used the term "creatures." This does not mean that they were animals. They may have been either plants or animals.

Several types of creatures are represented in these fossils. There are two which probably are primitive forms related to the blue-green algae. Another may be related to the iron bacteria; still another may be related to the coral. And there is, as well, a mystery creature which resembles nothing now living. It is very small, as are all the fossils. The mystery creatures (for which there is yet no name) measure from 20 to 30 microns and seem to stay within those limits. (A micron is 0.000039 inches, a thousandth part of a millimeter.) It consists of an inner and an outer sphere. Between the two spheres are fitted formations that look somewhat like hamburger buns. So far the greatest number of these "buns" found in any one of the creatures is thirteen.

No one has the least idea of what kind of thing it is. But



Fossil forms possibly related to blue-green algae (left) and "hamburger bun" forms (right) were found in Gunflint chert.

whatever it may be, it is not a freak. It was a persistent form of life. More than a hundred fossils of it have been found.

In 1964 another discovery of possible Precambrian life was announced—this time also from Australia. If the things which were found do, indeed, turn out to be fossils, they will be the oldest of all known forms of life.

The evidence was reported by C. G. A. Marshall, J. W. May, and C. J. Perret, of the departments of geology and microbiology at the University of Western Australia, Perth.

There is at the moment no solid proof that the objects which were discovered in Australian rocks are, in fact, the fossils of once-living microorganisms, but the observations made so far point strongly in that direction.

If the objects are fossils, they are older by some seven hundred million years than the fossils found in the Gunflint chert. The Australian rock has been radioactively dated to two billion, seven hundred million years ago.

The apparent microorganisms are only a few microns in size and are situated in a transparent mineral which cements

the quartz grains of which the rock is made up. The transparent cementing material may basically be opal.

Three types of the objects have been found, one red (called the R type), one yellow (the Y type) and one mixed red and yellow (the M type). The R type is composed of hematite, the mineral which makes up many high-grade iron ore deposits. The Y type is goethite, a yellow ferric hydroxide, another iron mineral. If the objects are fossils, all this means is that the structures of the creatures were replaced in the petrifactive process by these minerals.

The R and Y types come in several different forms. The Australian scientists believe that these different forms may represent successive stages in hypothetical life cycles.

The R type in its simplest form is a sphere. A long form, the scientists believe, may represent an elongation of the animal, during which process a restriction in the center of the elongated shape makes the longer shape appear to separate. This produces, in cross-section, a form which resembles a figure eight. What appears to be a definite cell wall can be seen between the two nearly spherical shapes. A dark dot may be present inside either or both of the loops of the figure eight.

It may be possible, the Australian scientists speculate, that the animal did separate and become two animals. But the more likely speculation is that the elongation, once started, continued at right angles to its former direction, with further restriction and further elongation. This resulted finally in a closely packed aggregate of spheres—in other words, a colony of the creatures.

The Y series seems to show a strange double-budding process unlike anything that has ever been observed in a presently living organism. Once again, the buds do not seem to break off, but the budding continues until a roughly spherical "colony" is created. The budding lobes give the "colony" something of the appearance of a raspberry.

The M type seems to be relatively rare. It has a core of

what appears to be the Y objects partially surrounded and at times more or less enclosed by a group of the R objects.

No carbon, always an indication that life may have existed, has been found in association with the objects. Nor is there any other direct proof that the objects are fossils.

Yet no one, so far, has been able to conceive of any inorganic process which would give rise to a series of such non-crystalline masses of such constant dimensions, assembled into such markedly lifelike patterns.

One guess might be that the objects are spores of higher organisms, the vegetative substances of which have entirely disappeared. But such an explanation does not explain the strange evolution of shapes which the objects assume.

The finds in Australia and in the Lake Superior region may indicate that we are finally on the way to finding out some of the things we want to know about Precambrian life. But so far it is no more than a beginning. The fossils as yet aid us but little in understanding the era, as do the fossils from other periods of geological history. There are as yet too few Precambrian fossils, found in too few places, to afford us the development of an evolutionary trend.

And why did the apparently great and varied population of the Precambrian leave so poor a physical record? There are two possible reasons, both of them relatively simple. The early life forms probably were soft-bodied and would have been fossilized only under the most favorable conditions. Many of the fossils which did form probably were destroyed by the long periods of Precambrian erosion. There is some evidence that the earth had undergone a long period of erosion immediately prior to the beginning of the Paleozonic era. Other Precambrian fossils may have been buried deep beneath the surface in the great upheavals of later ages.

Furthermore, most Precambrian life forms were probably microscopic, and microscopic fossils are difficult to find. It was

only by the sheerest sort of luck that Tyler peered through his microscope to find the fossils in the Gunflint chert.

Finally, fossils are where you find them. We may, quite simply, have never looked in the proper places to find Precambrian fossils.

We know a little—a very little—of the geography of the Precambrian. We know a very little of its life forms. Likewise we know very little, but something, of its climate.

It is possible that the early days of the Precambrian overlapped that time when the earth still was in the process of cooling off. If this were the case, then the earliest ages of the era would have been wrapped in a steamy atmosphere. We know that, at least in the Lake Superior region and in Scandinavia, a good part of the Precambrian was marked by violent volcanism, which would argue that the earth still was in the throes of shaping its surface. And the history written on the stone walls at the bottom of the Grand Canyon tells of extensive deserts.

The fact of the matter seems to be that during its long duration, the era knew many kinds of climate. For as well as the evidence of deserts, of extensive volcanism, of seas, there also is evidence of continental glaciation. Precambrian glacial deposits exist in many parts of the world and appear to represent at least two Ice Ages, one in the Middle Precambrian and another near the era's close.

Glacial deposits exist in northern Utah beneath the Cambrian formations. There are indications that at one time during the Precambrian an ice sheet more than a thousand miles in width lay across central Canada. In south-central Australia Precambrian glacial drifts lie to the depth of 600 feet. Other such deposits are found in southern Africa, in the Yangtze valley in China, in India, Norway, and eastern Greenland. The widespread distribution of this glacial material makes it quite clear that the glaciation was not local, but of worldwide extent.

6. THE CAMBRIAN

Time of the Trilobite

HISTORICALLY, in the geological sense, one stands on solid ground for the first time in the Cambrian period, the first of seven periods in the Paleozoic era.

Because of this, it is natural for one to fall into the error of regarding this ancient period as a sort of starting point, as some kind of beginning. But, while the Cambrian period lies some 600 million years away in time, it actually is not the beginning of anything at all.

If we could compress the five billion years of our earth into a hundred days, we already would have counted 88 of those days before the Cambrian began. The remaining 12 days would represent all the time from the Cambrian up to the present day.

There is no better way to realize the vast amount of time which lies behind the Cambrian period than to consider that in the Cambrian fossils all the different phyla of animals that we know today are represented, with the one exception of the vertebrates, the subphylum of back-boned animals. In the Cambrian fossils we are not dealing with simple forms of life, but with highly organized creatures that in many respects of their

structure are almost modern. From the evidence we find in these fossils, it becomes fairly clear that more than half the drama of evolution had been enacted before the Cambrian period began.

What is new in the Cambrian is the appearance of fossils in abundance. With the appearance of numerous fossils, the dating of rock strata becomes possible. Thus, in the Cambrian period, for the first time we can begin to construct a comparative chronology of our earth's history.

The break between the Precambrian era and the Cambrian period is sharp so far as fossils are concerned. The earliest Cambrian rock in many instances has fossils in profusion, while the oldest layers of the Precambrian are destitute of fossils so far as we now know.

Life in the Cambrian springs forth in full bloom. Here (except for the vertebrates) are the primordial ancestors of all the things which live upon the earth today.

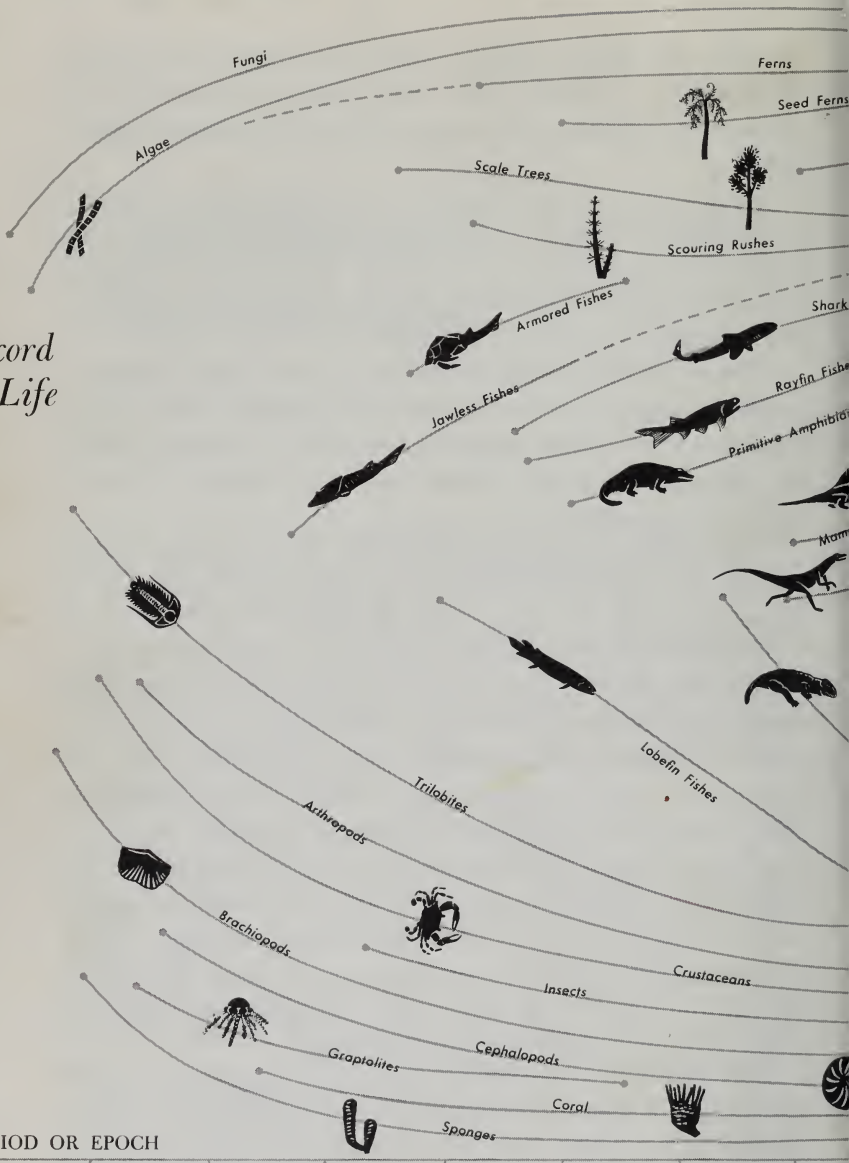
We have noted earlier that the absence of fossils in Late Precambrian rock may be due to the long period of erosion which came at the end of the era. There may be yet another reason to explain the barrenness of the Precambrian and the sudden and dramatic appearance of fossils in the Cambrian. This explanation suggests that somewhere, somehow, in some brief span of time, earth's life developed shells and chitin coverings. Chitin is similar to the kind of stuff of which our fingernails are made; it also is the body covering of many kinds of hard-shelled insects. The development of hard parts such as shells or chitin would have vastly improved the chance of a fossil being left behind once a creature died.

But why, in a relatively short span of geologic time, should the animals of the Late Precambrian have developed hard parts to burst in fossil glory into the Cambrian? No one knows yet, of course, but some speculations may be close to the truth.

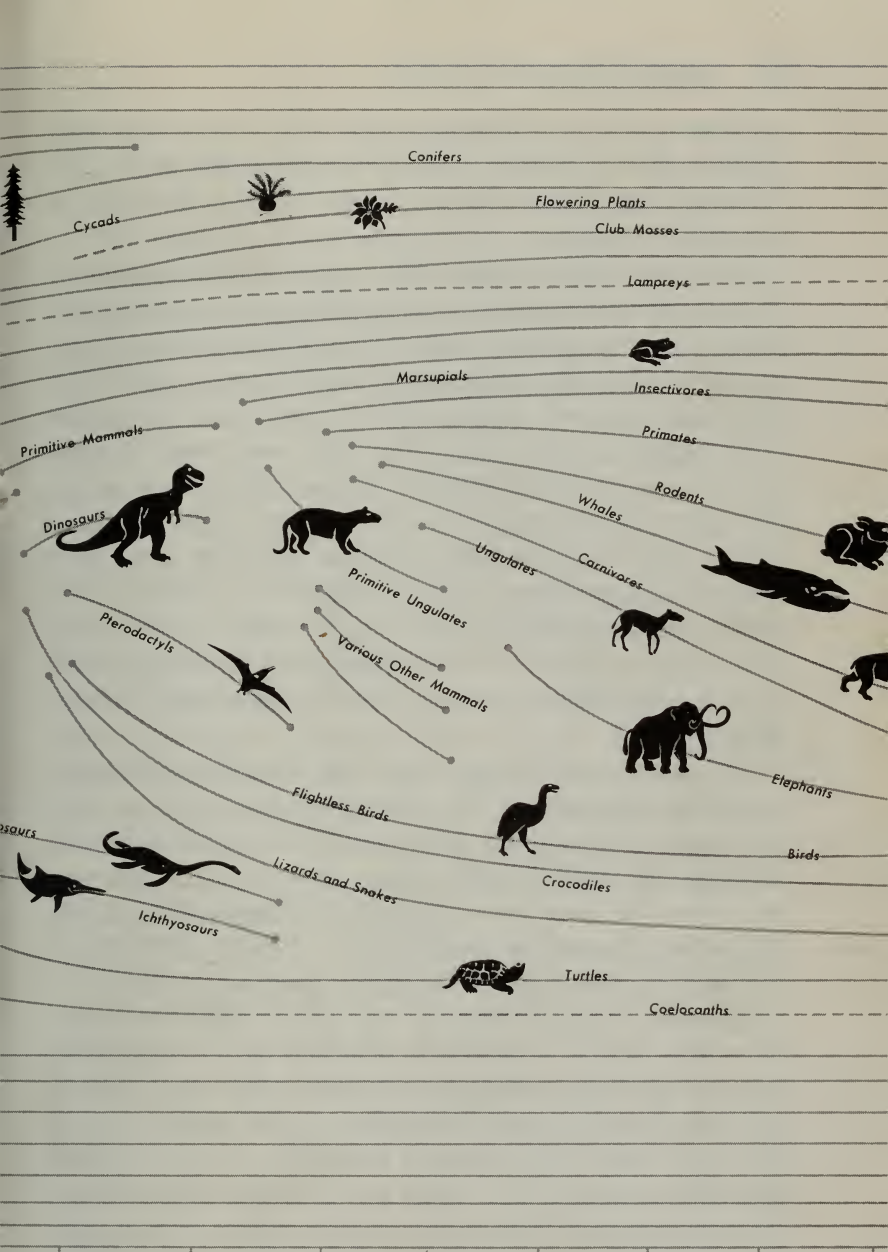
Let us suppose that up until a relatively short time before

GEOLOGICAL TIME CHART

Record of Life



PERIOD OR EPOCH	Precambrian	Cambrian	Ordovician	Silurian	Devonian	Mississippian	Pennsylvanian	Per
Millions of years	600	500	425	405	345	310	280	
ERA	*PALEOZOIC*							



ssic	Jurassic	Cretaceous	Paleocene	Eocene	Oligocene	Miocene	Pliocene	
180		135	65	58	36	25	13	1.0
MESOZOIC			*CENOZOIC*					

the beginning of the Cambrian period all life forms were either herbivorous or scavengers, eating either plant food or the dead bodies of their fellows. It was a time of peace; there was no such thing as killing.

But let us further suppose that for some reason the numbers of creatures suddenly increased—that there was a population explosion. Or that suddenly some of the primitive creatures began to grow much bigger and began to need more food. Both things may have happened—some of the creatures may have grown much bigger and there may have been many more of them. Up until that time there had been plenty of food for everything. But now, with so many more and so many bigger mouths to feed, a competition for food developed (for there would have been no more food than there ever had been). Under the pressure of food competition, some of the larger creatures may have turned to killing to obtain their food—no longer content to wait until another creature died a natural death to grab it for food.

The process of evolution has a way of dealing with almost everything that happens. Once killing started, evolution would have been set in motion. To protect those things which stood in danger of the killers, the natural forces of evolution, over the course of many ages, would have developed an armor, which took the form of shell or chitin. With the development of armor, the possibility of fossilization increased greatly.

Another theory is that the seas of the Precambrian may have been lacking in dissolved carbonates out of which shells or other hard parts might have formed. Once the Cambrian seas had enough dissolved carbonates, shells became possible and were formed. The need of protection may have existed, but with no possibility of being met until the composition of the ocean changed. This theory, however, suffers from the fact that primitive algae, through a good part of the Precambrian, were able to find plenty of carbonates with which to build

their reefs. And even if the carbonates had not been at hand, creatures needing protection could have developed chitin armor, which has no need of carbonates, but is based on nitrogen.

The Cambrian period began about 600 million years ago and lasted for 100 million years. The Paleozoic era, of which it marks the beginning, lasted for a matter of 370 million years.

Those 370 million years bristle with significance. The era began with the land bare of any vegetation; before it ended vast jungles flourished in the coal swamps. It began with animal life confined to the water; its close saw the rise of the great reptiles that were to rule the earth for more than 100 million years. During most of the era the climate was equable and mild, a sort of eternal summer; its end brought a time of reckoning, with the first appearance of seasonal climate and the dying out of many life forms which were unable to survive anything but a summer climate.

The Paleozoic also was a time of vast epicontinental seas, which repeatedly encroached upon the land. At times these shallow seas covered more than half of what now is North America. An epicontinental sea, as was pointed out earlier, is that portion of the ocean which creeps over a continental area. Such seas are always shallow. Hudson's Bay and the Baltic Sea are modern epicontinental seas.

At the very outset of the Paleozoic, the Cambrian sea began to encroach upon the land. Before the close of the Cambrian period more than 30 per cent of North America was covered by water.

The main features of the period in North America were two geosynclines. A geosyncline is a trough of submerged land, generally some hundreds of miles long and some scores of miles wide. It is an area into which vast sedimentary deposits settle, and it usually has a tendency to sink ever lower under the weight of the deposits so that instead of filling up with sediments, it continues as a trough.

One of the Cambrian geosynclines is known as the Appalachian geosyncline. Lay a ruler on the map of North America, with the upper edge on the northern tip of Labrador and the lower edge on the mouth of the Mississippi River. The edge of the ruler will run, with some variation, along the course of the geosyncline. The other geosyncline, called the Cordilleran geosyncline, ran north and south roughly along the present course of the Rocky Mountains. Both of the geosynclines were filled by epicontinental seas.

East of the Appalachian geosyncline stood a land which is not there today. It is called Appalachia. Its western edge stood on what is now the eastern seaboard of the United States and southeastern Canada, and it extended an unknown distance eastward, probably to the edge of the present continental shelf, which lies some 200 miles beyond the present coastline. During most of the Cambrian period, Appalachia probably was a mountainous land and down from it poured a flood of sediments which came to rest in the Appalachian geosyncline.

Much the same condition existed in the west. Westward from the Cordilleran geosyncline lay the ancient land of Cascadia. It covered what are now the coastal ranges of Canada, Washington, Oregon, and California. Like Appalachia, it extended westward, probably as far as the edge of the continental shelf. Cascadia also probably was mountainous.

Between the seas that filled the two geosynclines, the interior of the continent appears to have been a vast plain.

Before the period came to an end, another geosyncline developed across northern Mexico and part of Texas, at times connecting the other two geosynclines. This third geosyncline is known as the Ouachita trough, and the mountainous land that lay to the south of it is known as Llanoria.

This was the situation which existed in North America generally through a greater part of the Paleozoic era. At times the seas retreated, at times their level moved higher to cover

LATE CAMBRIAN

greater areas of the continent. But, by and large, the three geosynclines remained, flanked by their three borderlands, with a fairly stable land lying in the interior of the continental mass. The three borderlands appear to have been restless. Worn down by erosion time after time, they rose again and again. But they did it decently and deliberately, without too much violence. They had a lot of time to wear down and rise again; in the Cambrian alone they had a hundred million years.

Twice during the Cambrian the seas retreated. They may, in fact, have retreated entirely off the continental mass, to let all the land stand dry. But each time they came back again. This probably can be explained by the rise and fall of the

world's sea level rather than by any particular rise or depression of the land mass itself. A rise in the ocean's level may have come about to start with by the partial filling of the ocean's bed by the sediments which, over millions of years, had been washed into it. There is some reason to believe that in the Late Precambrian the earth's surface underwent a period of erosion which lasted for several, perhaps many, million years. An erosive period of this duration would have scoured a vast amount of sand and other debris off the face of the earth. Much of this would finally have been carried into the ocean. What was still left on the surface would have been re-sorted and laid down as sedimentary rocks when the epicontinental seas swept over much of North America at the beginning of the Cambrian.

Or the world's sea level may have risen as a result of an upheaval of rocks which lay beneath the ocean floor. The retreat of the water from the land may, the reverse of this, have been caused by sea floor disturbances which served to deepen the ocean basins, causing the water of the epicontinental seas to drain back into the basins. It is fairly evident in any case that the advance and retreat of the epicontinental seas over North America during the Cambrian period was caused by fluctuations in the ocean level, and not caused by any submergence or rising of the land. The Cambrian was a quiet period. While the lands bordering the ancient geosynclines rose and wore away, time after time, the rest of the continent, and apparently the rest of the world, remained stable.

Toward the end of the period there was some mountain-building in other parts of the world, particularly western Europe. But, while North America appears to have risen slightly at the same time, the rise was not marked and there were no new-born mountains.

During the Middle Cambrian the seas encroached still further on North America, filling a great part of what is now the

Mississippi valley and covering about 30 per cent of the continent.

At this time, as we mentioned, much of the land must have been covered by a fairly thick mantle of sand and other material as a result of the long period of Precambrian erosion. As the seas moved in, the water currents reworked this material and laid it down as sediments which finally became sandstone or siltstone. Rivers draining off the Canadian Shield brought in other large quantities of sand. Tongues of this sand can be traced in sandstone formations as far south as Pennsylvania. At St. Croix Falls, Minnesota, a layer of sandstone a thousand feet thick tells the story of a river that poured its freight of sand down into the Cambrian seas off the edge of the Canadian Shield.

The thickest and most impressive Cambrian rocks, however, are found in the Rocky Mountains and in some areas of the Appalachians. Here the tremendous amounts of sediments poured into the two major geosynclines were reared up as rocks in later ages when the continent underwent periods of mountain-building.

The Cambrian period ended with the epicontinental seas receding, leaving the greater part of the continent dry land, but still a low and flat dry land upon which the seas, in time to come, would find no trouble in again encroaching.

In Europe the story is much the same as in North America. The Early Cambrian saw the seas moving into only the northern reaches of the continent, but in the Middle and the Late Cambrian a good part of Europe was under water. As the period came to an end, the waters withdrew, as they did in North America, but in Europe they were hurried along by an upheaval of the land surface.

In South America there is evidence that a great geosyncline ran along the course of the present Andes Mountains.

During all the hundred million years of the Cambrian the

Middle Cambrian sea bottom.

land lay desolate. One is tempted to say that there was no life upon it. Saying so, one probably would be right; but there is just a chance that, at this time, a half billion years ago, a few feeble plants may have clung to the land at the water's edge. If they existed at all, they would have been very primitive, soft-tissued plants. Lacking roots and vascular tissue which would have enabled them to draw moisture from the ground, they could not have existed anywhere but in certain wet lowlands. Their existence would have been precarious at best. At a guess, if there were such plants, they would have resembled moss or lichens.

Two Russian scientists, S. N. Naumova and A. N. Krystofovitch, have reported finding spores of land plants in Lower Cambrian rocks in the Baltic area, and both spores and plant tissues in Middle Cambrian rock in Siberia. The evidence is there, apparently, but it is rather slight. Still, twenty years ago one would have been justified in saying there was no life on the Cambrian land surface. Now it seems there may have been.

But if primitive plants lived on the surface, they were the only life that lived there. Animals as yet had not learned to breathe the air.

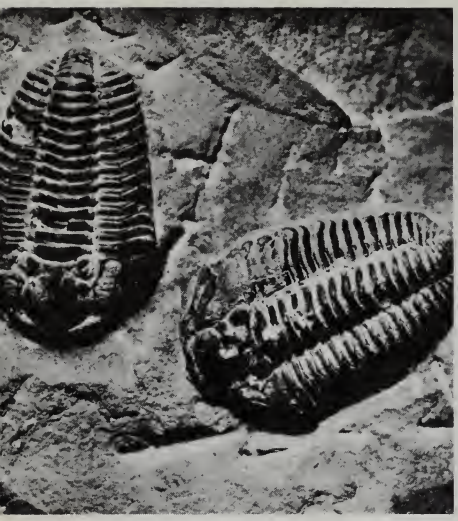
Lacking as life might be on land, the seas swarmed with it. Fossils of more than 1,200 different species of animal life have been found in the Cambrian rocks of North America alone.

When one thinks of the Cambrian, however, he thinks of one animal in particular—the trilobite. There are no such things as trilobites today, but during the Cambrian period they accounted for fully 60 per cent of all life in existence. They were crustaceans, and did not run to any size. Generally they ranged from one to four inches, although there was one monstor, named *Paradoxides harlani,* that ran to 18 inches and probably weighed ten pounds.

If you want to get an idea of what a trilobite looked like, turn over a stone or a piece of wood. Running out from under it will be any number of crawly things. Among them there is likely to be a wood louse (some people call them sow bugs). This little insect is in no way related to the trilobite, but in appearance it is the closest thing we have today.

The trilobite is a distant (a very distant) relative of the crayfish, the lobster, the horsehoe crab and other similar creatures which are alive today. Its body was divided into three segments and covered by a chitinous skeleton. It was equipped with delicate antennae, and had numerous legs for crawling or for swimming. It probably was carnivorous, killing other life for food, but also probably not above gobbling up an already-dead body if it stumbled over one.

The trilobite survived throughout almost all of the Paleozoic era, some 370 million years, dying out in the Permian period, the closing period of the era. During that time it managed to assume a lot of different forms. So far, we know of more than 1,000 species of trilobites, all of them trilobites, but each



Fossil trilobites in flat and coiled positions.

one a little different in its physical structure. And while the trilobite died out a matter of 230 million years ago, there is reason to believe that it was either the direct or indirect ancestor of all joint-legged invertebrates today. Invertebrates are animals without backbones. Back in the Cambrian days, so far as we can determine, all animals were invertebrates. The backbone had not as yet developed.

The trilobite is a guide fossil for the Cambrian rocks. *Olenellus,* a guide fossil for the Lower Cambrian, had a sharp, pointed tail. Several types of large-tailed trilobites are the guide (or index) fossils for the Middle Cambrian. A prong-tailed trilobite, *Crepicephalus,* is the guide fossil for the Upper Cambrian.

Trilobites made up about 60 per cent of the Cambrian fauna. Another 30 per cent was made up by the brachiopods. The brachiopods are shellfish which, to the average person, might look very much like clams or oysters. But because of certain differences in shell arrangement and hinging, they are not grouped with either clams or oysters. We still have brachio-

pods with us today: there are about 200 species of them still living. During the time since the Cambrian period, however, there have been thousands of species of them, all now extinct except for our modern-day 200.

As a rule, the Cambrian brachiopods were small, from half an inch to two inches across. The biggest of them, a giant measuring a foot across, lived during the Mississippian period, more than 300 million years ago.

Other animals which lived during the Cambrian period included sponges, jellyfish, several kinds of worms, and snails. A primitive family of corals, called *Archeocyathina,* built massive reefs during the period. The calcareous algae also were busy, as they have been through all the history of our planet.

One of the most unusual fossil beds ever found is located in Cambrian shale on Mount Wapta, near the town of Field in British Columbia. It was discovered quite accidently by Charles D. Walcott in 1910, when a pack horse turned over a slab of slate, revealing a wealth of fossils on the under side.

Cambrian rocks carry a profusion of fossils of those animals, such as trilobites and brachiopods, which had developed hard parts. But in the Burgess shale, high on the side of a Canadian mountain, dozens of soft-bodied creatures had left behind a record of their existence. Walcott found animals belonging to 70 genera and 130 species. Included were sponges, jellyfish, annelid worms (angleworms are annelid worms), and a number of arthropods (belonging to the same family as the trilobites).

The animals were preserved as a lustrous film of carbon imprinted on the cleavage planes of the slate. So wonderfully preserved were they that one could distinguish not only such small exterior details as bristles, scales, and antennae, but in many instances the intestinal tracts as well.

Obviously, special conditions must have existed to account for such a fossil bed. Geologists, attempting to recreate the

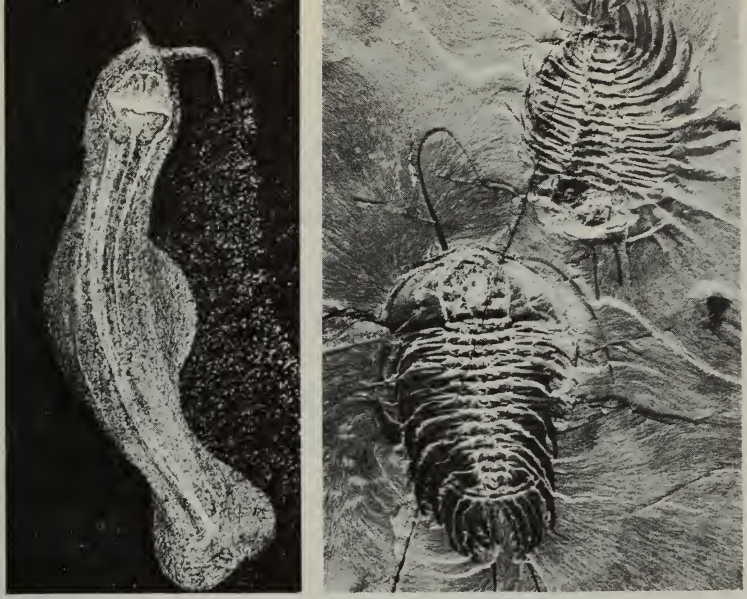
situation, are inclined to believe that the bed represents a particular section of sea bottom, which lay at a considerable depth below the normal sea floor. Over the years an extremely fine-grained mud accumulated there. Many of the little animals which lived in the water above the depression died and sank into the depression. This is a process which goes on to this day—the dying and the sinking of dead bodies into lower depths. In every body of water which exists on the earth today, this rain of death goes on.

Under ordinary circumstances, both in the Cambrian and now, many of the dead bodies would have been snapped up by scavengers before they ever reached the sea floor. Most of those which escaped the scavengers and came to rest on the bottom would have been ingested by little burrowers that root in the mud to find their livelihood.

But, in this particular instance, it is unlikely that many burrowers would have ventured into the great muddy depression. The dead bodies that fell into the fine-grained mud at the depression's bottom would have remained there to decompose.

Another thing to consider is that the water within the depression would have been stagnant. It would have lain as a body of trapped water, not taking part in the general circulation of the great body of sea water. As a result, it would have become deficient in free oxygen. (Such deoxygenated areas exist in many places today in the ocean bottoms. Water in some areas in the bottom of the Black Sea is one example.) Because of the lack of oxygen, the depression was a death trap. Nothing could live there—finally not even the bacteria which would otherwise have caused the decomposition of the bodies which fell into the ooze.

Because of the lack of oxygen, free hydrogen, needing to combine with something, would have combined with sulphur from the mud and organic matter, resulting in hydrogen sulphide. Hydrogen sulphide is what imparts the horrible smell to



Fine details of structure are visible in fossils of worm (left) and trilobites (right) from Burgess shale.

rotten eggs. In sufficient concentrations, it is a deadly poison.

The ooze at the bottom of this ancient Cambrian depression would have reeked with hydrogen sulphide. Occasionally, perhaps, when storm waves swept across the shallow sea, the bottom muds would have been roiled and clouds of the gas released, rising into the water and poisoning any life that came into contact with it.

Thus, century after century, the dead animals rained out of the sea above into the depression, settling into the mud at its bottom. Since no scavengers or bacteria could exist within the mud, the bodies (or most of them) remained intact. Some of them, covered by the mud, became the fossils that were found in 1910. As the sediments piled up, their bodies were pressed into the matrix of the mud—which in time became a shale—and were thus preserved, as a tiny film of carbon, for more than half a billion years.

We know that all Cambrian life existed in the water, if

one excepts the possibility that some very primitive plants may have grown at the water's edge or in some low, wet areas. We know that, with very few exceptions, perhaps with no exceptions, the land lay barren. There was only rock and water. In a few places soil may have come into being.

But aside from this, what kind of world was the Cambrian?

Because we know that glacial conditions existed toward the end of the Precambrian era, a good guess would be that at the beginning of the period the climate may have been somewhat cooler than normal. But if this were the case, the climate apparently warmed as time went on. There is evidence that climatic zones were not as sharply defined as they are today and that many forms of life had a much wider range than would now be possible. The life zone extended much closer to the poles than is the case today. Everything points to a gentle summer climate. This is what would be expected in a world where water covered a greater part of the globe than it covers now. A water world is apt to have a milder climate than a world with large land surfaces.

Certain Cambrian rocks in Wisconsin and Texas once were cross-bedded sands, possibly sand dunes, and in them are pebbles showing marked evidence of wind erosion. This is evidence that toward the close of the Cambrian period some desert areas may have occupied part of the stable interior plain of North America.

The Cambrian was a time of quietness, a time of getting ready. In a little time (geological time, that is) there would be many significant changes. The back-boned animals would appear. Plants would move out to cover the land. The first insects would show up. Fins would develop into feet and gills into lungs and strange, unwieldy creatures would finally walk the earth.

But not yet. Not in the Cambrian. The Cambrian was too early.

7. THE ORDOVICIAN

The Beginning of the Backbone

IN THE BEGINNING life was a single cell. It was capable of certain responses to certain stimuli. It moved toward food; it fled from danger. And this was fine, for the cell knew instinctively what it wanted and what it must avoid. For it, the business of living was entirely automatic.

But when, through the natural processes of evolution, some forms of life advanced from a single cell to a group of cells, forming a slightly more complicated form of creature, responses to stimuli also became more complicated. One cell could act instinctively, but without communication a group of cells could not. Without communication, their responses would have been uncoordinated.

As these ancient life forms evolved into multi-celled animals they developed a communication system that was the primitive beginning of a nervous system. As the creatures became more and more complex, it was imperative that the nervous system should keep pace. The main nerve cord grew bigger and thicker, the nerve fibers branching out from it became more complicated. A nerve structure that served as a central control system developed, and that was the beginning of a brain. Specialized

groups of cells sensitive to certain conditions, such as light or sound or odor, also developed. In time, the light-sensitive cells became eyes, the other specially-sensitive cells became other sense organs. The creature's awareness of its environment became more acute, and its reflexes became more conditioned to conform and react to that environment.

In most lower animals the main nerve cord ran along the belly, where it is best protected. But somewhere, sometime in the ancient past, probably only in one animal, through the long process of evolution, the cord shifted to a location along its back and was protected with gristle. Such a back-located cord is called a notochord, or a "back string." Finally, as time went on, the notochord came to be encased in a backbone, a string of vertebrae which protected it better than the gristle, but still retained flexibility.

With the development of the notochord a new phylum of animals came into existence—the *Chordata.* When the notochord developed into a backbone, a new subphylum came into existence—the vertebrates.

So far as each of us is personally concerned, this undoubtedly can be ranked as the greatest event in all of the history of life on earth. For we are vertebrates.

No one knows what creature first developed the notochord; it is something that we may never know. Best guess at the moment points to the phylum *Echinodermata,* which includes the starfish and the sea urchins. This is not to say that the starfish, in its adult form, resembles a vertebrate in any way. But in its larval stage, there are some points of resemblance, too complicated to try to go into here, which hint that the *Chordata* may have arisen from the phylum to which the starfish belongs. Some biologists are inclined to believe that the echinoderms and the chordates arose from a long-lost common ancestor. The echinoderms took one evolutionary road, while the chordates took another.

First evidence of the vertebrates appears in the Ordovician period, which follows the Cambrian period. At a glance the evidence is not too impressive, but it seems undeniable.

Rocks of the Middle Ordovician have yielded a few petrified bony plates of extremely primitive fish. The fossils have been found near Canyon City, Colorado, in the Big Horn Mountains of Montana, and in the Black Hills of South Dakota. In every case the bony plates are fragmentary. But comparison with well-preserved fossils of fishes found in the Late Silurian and Devonian rocks unmistakably identifies them as plates from an order of fish known as *Ostracodermi.*

Ostracoderms were protected by strong bony armor which covered the foreparts of their bodies. Their tails and the rear parts of their bodies were left uncovered to provide flexibility and, thus, motive power for swimming. They did not have fins, which were a later development. They had no jaws, and in most species their mouths were located on the underside of their heads. This, and the fact that their eyes were placed well up on the top of their heads, indicates that they were bottom feeders, grubbing in the mud for their food. It is believed they lived in fresh-water ponds and rivers rather than in the sea.

In later ages, these first primitive fish lost their armor, trading its rather doubtful protection for increased agility and speed.

Restoration of an ostracoderm.

Encumbered by the weight and rigidness of the armor, they must have been sluggish and easy prey for predators.

Our greatest knowledge of these strange fish comes from later periods of time, when their fossils are more abundant. But the fragmentary fossils found in the Middle Ordovician is substantial proof that they existed in that period, which began about 500 million years ago and covered some 75 million years.

However, the probability is—though their fossils are yet undiscovered—that vertebrates existed long before the Middle Ordovician. The ostracoderms were well-developed vertebrates. It seems only reasonable to suspect that simpler forms existed for millions of years before the primitive fish appeared.

Development of the vertebrates was a great step forward in body engineering. The first function of the backbone, of course, is to protect the spinal cord. But it likewise opened up new possibilities for body structure. It served as a girder from which its owner could hang bulk and size. Heretofore, life had been small; here was the opportunity to achieve some size. The backbone served also as an arch upon which could be hung an internal skeleton, getting rid of the unwieldy and restricting exoskeleton, or outer skeleton. A cage of ribs to enclose the vital organs in the chest could be suspended from the support furnished by the backbone. It also could serve as a platform for legs, and to it could be attached jawbones that, in turn, could carry teeth.

The Ordovician was a time of warmth and water. The fauna in the sea spread far north and south, perhaps as far north as the northern tip of Greenland. There may have been no ice anywhere in the world, perhaps not even polar caps. The circulation of the atmosphere, unimpeded by mountainous areas, would have been unlike any atmospheric pattern that we know today. Warming ocean currents probably circulated widely from the equator, providing a fairly even distribution of heat over the face of the earth.

The fauna of the Ordovician seems to have paid little attention to climatic zones, and the best explanation seems to be that there were no sharply defined climatic zones. Corals are warmth-loving animals. Today they are found only in warm seas. During the Ordovician they were busily engaged in building reefs all across Arctic Canada, from Alaska eastward to northern Greenland.

The seas, at the close of the Cambrian period, had drained off most of North America. But now, at the beginning of the Ordovician period, they came creeping back again. The uplift that had brought the Cambrian to a close in North America had been a gentle movement. There had been no folding or faulting of the rocks, no great mountains had been raised. As a result, the Ordovician rocks lie directly upon the Cambrian with little evidence of any discontinuity. In fact, it often is difficult to distinguish one from the other.

This would seem to indicate that the uplift at the end of the Cambrian had been so slight that little erosion resulted from the time the seas retired until they returned again. There were no great heights of land. North America probably was fairly level. The streams ran slowly, and as a result there was little transport of material. Even the normally mountainous Appalachia had been eroded during the latter days of the Cambrian into a fairly level plain and did not rear up into mountains again until early in the Middle Ordovician.

The seas first flooded back into the ancient geosynclines, then swept across much of the rest of the continent, even covering part of the Canadian Shield, which throughout the greater part of earth's history has remained high and dry.

At times during the Ordovician period more than half the continent was inundated. During these times of maximum flooding, the land that remained above the epicontinental waters existed as islands.

Twice during the 75 million years of the Ordovician the

seas apparently retreated, but in each instance they came back again. During the comparatively brief times that the continent was dry, the freshly-laid sediments of the now uncovered sea bottoms were subjected to erosion and in some places entirely washed away.

At the height of the submergences, North America was a cluster of islands. In addition to the circling borderlands of Appalachia, Llanoria, and Cascadia, four areas in the interior of the continent remained above water. None of these four areas was mountainous. They probably extended little above the level of the rest of the continent, but it appears they had a tendency to rise slightly, enough to stay above sea level, as the surrounding land gently subsided. Today the four areas stand as groups of ancient rock, surrounded by newer rock, laid down by the ancient seas.

The four areas were the Cincinnati Arch, which runs roughly from the present Nashville, Tennessee, northward through Cincinnati and western Lake Erie into Ontario; the Ozark Dome of southwestern Missouri, the Adirondack Dome of northeastern New York, and the Highlands of Wisconsin.

Most of the rocks of the Ordovician period are, as you might guess, marine in origin. Rocks formed from sediments which were washed into the ocean from the land are found only in a few localities.

Most of the rocks are limestone and dolomite, formed by the tiny marine life which removed calcium carbonate from the water to form their shells. Dying, they sank to the bottom, the calcium carbonate of their shells forming a limy deposit.

Ordovician rocks were first extensively studied in the state of New York. As a result, many of the Ordovician strata bear New York names.

At the beginning of the period, the seas apparently spread rather rapidly. Early in the Ordovician the sea filling the Cordilleran geosyncline covered the present Rocky Mountains area

from the Arctic Ocean to southern California. In the east the waters of the Appalachian geosyncline extended from Labrador to the Gulf of Mexico. At that time the ancient land of Appalachia apparently was low-lying. The sediments which were carried off it into the sea contained little gravel, but were, rather, a black mud. This argues that the streams which carried the sediment were slow-flowing and sluggish. The black mud formed the Deepkill shale, which extends from the mouth of the St. Lawrence River into New Jersey.

To the west and the south, where the mud did not reach, the seas laid down a thick formation of dolomitic limestone. This limestone is known as the Beekmantown formation and in places is 2,000 feet thick.

Limestones dating to the Early Ordovician also are found in some of the north central states and in the American Southwest, evidence that at some time during the early part of the period the sea spread over these regions.

In the west the situation was much the same as in the east. Cascadia apparently was low, for like Appalachia it, too, fed only mud into the sea. Beyond the shale which marks the limit of the mud, deep limestone was laid down by the seas occupying the Cordilleran geosyncline.

As the Early Ordovician came to an end, the continent emerged from the sea, but apparently for only a short time. Once again the seas came back into the geosynclines and then spread into the interior of the continent. Appalachia appears to have been rising at this time, but if so, it was a very gradual rise, for again its streams carried only mud, and none of the heavier sediments which would be moved by rushing water pouring off great highlands.

This mud formed the Canajoharie shale, which runs the length of the present Appalachian mountains. But the irregularity of the shale shows that at this time the western shore of Appalachia was fluctuating. As the sea crept in over the

land the mud was carried a shorter distance out into the water; as the sea receded the mud was carried a greater distance. As time went on the tendency was for the mud (marked by today's shale) to be carried farther and farther west. This is the evidence upon which is based the belief that Appalachia was rising. As it rose, it pushed the sea westward.

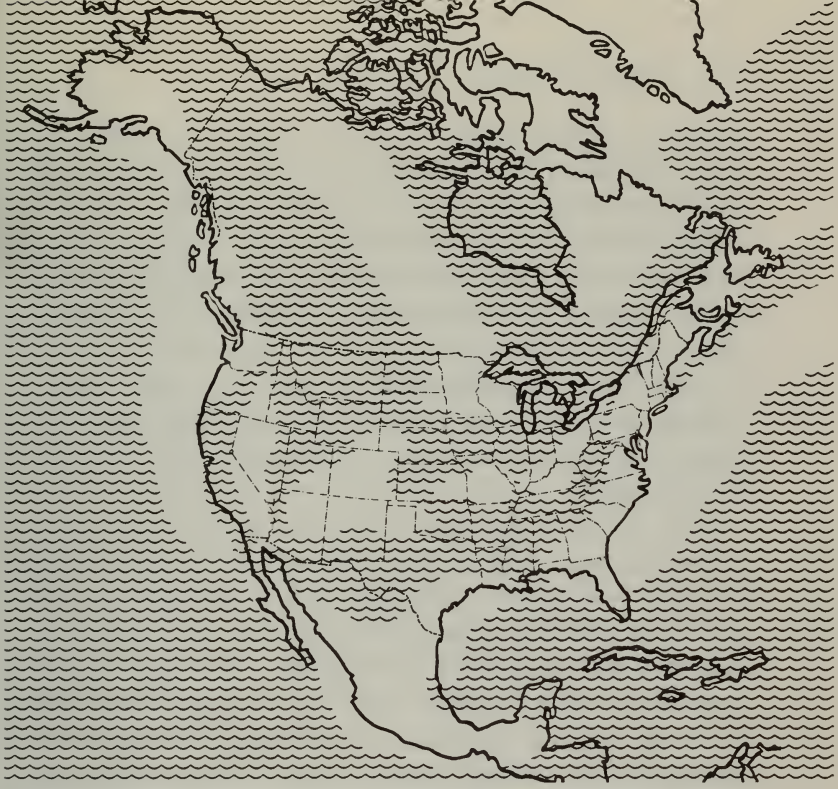
The limestone lying west of the shale, beyond the reach of the Appalachia mud, and formed in the clear sea, is known as the Trenton system. While the Trenton limestones cover a large area, they are only a few hundred feet thick.

As the water spread into the interior of the continent it covered areas which through long ages had been subjected to weathering and erosion and were, in consequence, covered by a thick mantle of sand and gravel. This mantle was worked over by the advancing water and laid down as the St. Peter sandstone. Extensive formations of this rock crop out in Wisconsin, Illinois, Iowa, Minnesota, Ohio, and Missouri. Once the debris had been reworked by the water, the sea laid down a thick limestone covering over it.

Much of the St. Peter sandstone is made up of pure quartz sand which has a rather frosty appearance. This frosty look comes about when the sand grains are rubbed together by wind action. It is possible that much of the sand which went into the St. Peter stratum consisted of ancient sand dune.

Late in the Middle Ordovician, a volcanic outbreak along the length of Appalachia gave unmistakable notice that the land was in the throes of uplift. For hundreds, perhaps thousands of years, this chain of volcanoes belched and thundered, filling the skies with ash and smoke.

The ash, now converted into bentonite, has been found in 16 states, all the way from Vermont to Alabama and as far west as Missouri and Minnesota. The thickness of the ash lessens westward and northward, indicating that the volcanoes were located on the western side of Appalachia and that the



LATE ORDOVICIAN

greatest activity probably centered in the vicinity of North Carolina.

At the same time there seems to have been volcanic activity in Alaska and British Columbia.

The seas reached their greatest extent in the Late Ordovician. It was during this time that a great part of North America existed as a group of islands. This mighty prehistoric sea has been named the Richmond Sea, after Richmond, Indiana, where the limestones which it deposited were first studied.

By this time Appalachia was rising swiftly. Savage, roaring streams, tumbling off the highlands and mountains, washed such great amounts of debris into the sea that in time a vast coastal

plain was built out from the western shore of the rapidly rising land. The mud of this coastal plain, exposed to the air, oxidized and turned bright red in color. Today it is preserved in the Queenston shale. There is evidence that at one time the edge of this coastal plain reached the vicinity of the present Niagara Falls, while the mud swept across the bottom of the bordering ocean reached as far as Ohio.

But while Appalachia rose, the west was quiet. Cascadia still remained low and while there was volcanic activity in Alaska and British Columbia, it apparently was no more than local activity.

The uplift of Appalachia culminated in the Taconian Disturbance, a mountain-building event which thrust up and folded the rocks in western New England, New York, and Pennsylvania. It is possible the mountains were of great size. At the same time a gentler uplift thrust the Cincinnati Arch slightly upward. This was not a spectacular movement, but the uplift, which continued into later periods, was enough that a ridge of land extending from Ontario into Tennessee formed, during much of the Paleozoic era, a boundary between the eastern and western deposits laid down by the various epicontinental seas.

In Europe the Ordovician also was a time of vast epicontinental seas. For a time northern Scotland, much of western and southern Scandinavia, and Finland lay under the Icelandic sea. South and east of the sea stood the great Caledonian geanticline, a ridge of highlands that separated the southern from the northern waters. South of the highlands were the British and the Baltic basins, which extended without a break from Ireland across central Russia. Nearly all of Spain and Portugal and the most of France apparently remained dry land throughout the period.

Southward lay the West Mediterranean Basin, which submerged a slice of eastern Spain and southern France, then swept in a great arc to join the Baltic Basin in Poland. Much

of Germany, all of Czechoslovakia, Austria, Hungary, Italy, and Switzerland were covered by the waters. The Balkan peninsula, southern Russia, and Asia Minor persisted as land through the greatest part, if not all, of the period. Late in the period nearly all of Spain and Portugal and most of France were submerged as seas surged across the land. In Africa northern Morocco was also under water.

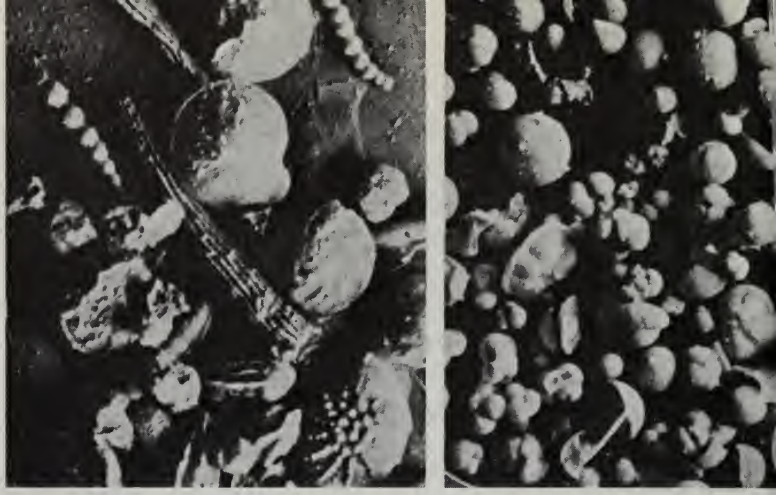
In Australia and New Zealand a good deal of Ordovician rock is found, evidence that during at least part of the period these lands were covered by water. In some places, however, there are no signs of rocks laid down during the Middle Ordovician, Upper Ordovician strata lying directly atop Lower Ordovician. In South America rocks from the period are present in northern Argentina, the Bolivian plateau, and eastern Peru.

In Europe the orogeny which closed the period was most pronounced in Wales, the north of England, and the Scottish highlands. Here the rocks were strongly folded and mighty mountains reared into the sky.

In eastern Asia the land surface also rose at the end of the period and stayed above sea level for millions of years. In that area of the world rocks of the next two geologic periods are missing. Water did not again invade the land until the Carboniferous period.

We have evidence of the first known vertebrates in the Ordovician period, but the world still was given over almost entirely to invertebrate life. The Cambrian fauna carried over into the following period, with some notable additions and developments. Some of these new life forms undoubtedly evolved during the Ordovician; others of them may have been present in the Cambrian, but failed to leave any fossils—or, more likely, may have left fossils which we have not found.

Toward the end of the Cambrian a large tribe of microscopic beings came into existence which flourished in the Ordovician and continue, undiminished, up to the present day. These



Fossil *Foraminifera* (left) and modern *Foraminifera* (right).

are the little protozoans known as *Foraminifera* and *Radiolaria*. There are a great many species of them.

All of them start life as little specks of protoplasm, very similar to the amoeba. Early in life, however, the foraminiferans begin formation of a tiny shell made of calcium carbonate, which they obtain from the water. The shells are pierced by tiny holes, out of which the animal extrudes a number of streams of protoplasm, which form a filmy network around the shell. This network ensnares and digests food. Some species of foraminiferans are content with building one shell and letting it serve them for a lifetime. Others, however, build new chambers to their shells, adding them at will and moving about from one chamber to another exactly as we might move about from one room to another in our house.

Radiolaria are similar to *Foraminifera* in many ways, but instead of shells, they build external skeletons. The skeletons are built of silica rather than calcium carbonate and take, according to the species, hundreds of different forms. All of them are delicate and beautiful and fantastic. Many of them bear strange resemblance to elaborate ornaments such as might be hung on a Christmas tree.

All such marine protozoans are so small they can be seen only under a microscope, and yet there were (and are) so many of them that they are a factor in the building of rocks. The famous white cliffs of Dover on the English Channel are made of the shells and external skeletons of such tiny creatures. Today much of the ooze of the ocean beds is formed of the remains of present-day protozoans.

A new, strange creature which first appeared in the Ordovician period was the graptolite. The graptolite was not a single animal, but a colony of animals which co-operated to build a many-armed body of chitin. These bodies, depending on the species of animal, assumed a multitude of shapes. Tiny cubicles or chambers were incorporated inside the body, each chamber to accommodate a member of the colony. The members were little tentacled creatures called polyps. Some of the graptolites were floaters, riding free in the tides and currents of the ancient seas, some were equipped so that they could attach themselves to a piece of sea weed, which served to buoy them up and to carry them about, others were suspended in the water by a gas-filled bag, still others were anchored, either to the sea bottom or to rocks. There are no graptolites today; they died out during the Mississipian period.

Crinoids also show up as fossils for the first time in Ordovician rocks. Although they are animals, they appear to be flowers. Some of them still exist in the oceans today and are called sea lilies. The body of the creature looks exactly like a stem and is anchored to the sea bottom or a rock. The head, if one can call it that, looks like a flower. The animal belongs to the same family as the starfish. Crinoids are not too common today, but during the Paleozoic era they existed in great numbers. There were many different species of them and it is likely that the different species came in different colors, heightening the illusion of their being flowers and not animals.

Another new neighbor in the Ordovician was the cephalo-

pod, related to the present-day nautilus and the giant squid. The giant squid, as a matter of fact, is the largest invertebrate animal of all time. Cephalopods are mollusks, true shellfish as distinguished from the brachiopods.

Cephalopod means "head-foot" a tag placed on the animal because the tentacles surrounding the mouth look like an array of feet. The shells of the ancient cephalopods came in a number of shapes and sizes. Some of them were long, some spiral. Size ranged from a few inches to one that was fifteen feet in length and ten inches across. This giant lived during the final years of the Ordovician period.

Fossils of true corals are found for the first time in the Ordovician period. Bryozoans (moss animals), which had appeared in the Late Cambrian, were in the process of rapid evolution in the Ordovician; the brachiopods were bigger and more abundant than they had ever been. And it was in the Ordovician that our old friends the trilobites attained the climax of their evolution. Ordovician trilobites differ from those of the Cambrian in that they had larger tail shields, more rounded and better developed, faceted eyes, and a new flexibility which enabled them to roll themselves up, tucking the head down onto the belly and wrapping the tail over it. At a guess, this might have been a means of protection against predators. Many fossil trilobites are found in this position.

Thousand of species of animals, some old, some new, are found in Ordovician rocks. Of the trilobites alone, there are more than 1,200 different kinds.

And at certain places in this world of invertebrates moved the first vertebrates, the armored fish. Perhaps not too many of them, perhaps not in too many places, but they were there, a shadow moving on the far horizon, a ghost of things to come.

8. THE SILURIAN

Beachhead

ONCE THERE WAS a little creature that probably was a relative of the trilobites or the sea scorpions (which we will get around to in just a little while). One day this creature was stranded on a sand bar or a mud flat. Quite naturally, it died, for it could not breathe the air and it could not stand the sun. Another day another of the creatures was stranded as the first had been, but the tide or a wave swept it back into the water just before it would have died.

Undoubtedly many millions of these little creatures died when they were stranded, and others came very close to dying, being swept back into the sea or covered by the water in just the nick of time.

This could have gone on for a million years or more. And some of these creatures, no matter how long it had gone on, would have kept on dying. But there were others of them that began evolving, slowly gaining the ability to stay for a longer time out of the friendly sea, learning to breathe the air and to keep from drying up when exposed to sunlight.

Finally there came a day—no one knows exactly when, except that it must have happened sometime during the Silurian

period—that some of the tiny creatures needed the sea no longer, but could live upon the damp edges of the sea. Perhaps by this time they *preferred* living on the edges of the sea, for there they had no enemies. They were, for the moment, safer on the land than they were in water. They were the first animals that had learned to live without the benefit of surrounding water.

It is probable that these first air-breathing animals were scorpions and millipedes. Many people call a millipede a thousand-legged worm.

The evidence of these creatures come from fossils in the Upper Silurian rocks, and there are not too many fossils. The fossil millipedes have been found only in Wales.

Up until this time no animal had ever lived on land. Perhaps at first the scorpions and millipedes had some need of water. Probably they lived part of the time on land, part of the time in little pools of water left behind when the tides receded. For a million years or more they may never have ventured far beyond the sea, living on its fringes. But as time went on they ventured further inland, eventually becoming true land residents.

It probably was at about this time that plants began to occupy the land in increasing numbers. You may remember that there is some evidence of land plants back in the Cambrian, but if this were the case, there is no evidence they did much evolving. There are no signs of them in the Ordovician. It is not until the Upper Silurian that we have further evidence —and again, this evidence is scattered and not too impressive. Few fossils of early land plants have been found in the Silurian rocks, and those only in England and Australia.

But even if there were no fossils of early plant life on land, many geologists probably would argue that land plants undoubtedly did exist in the Silurian period. For in the next period, the Devonian, there existed not only plant life, but

Middle Silurian sea bottom.

forests of trees with stumps more than two feet in diameter. For Devonian plants to have achieved this abundance and diversity, it is only reasonable to suppose they must have began their invasion of the land at a considerably earlier time.

It is considered likely that soft-tissued algae and some types of fungi began the first tentative invasion of the land early in Silurian times. It is likely that after a fairly short while tidal areas were carpeted with mosses and lichens and that for the first time in its history the face of the earth began to assume a tinge of green.

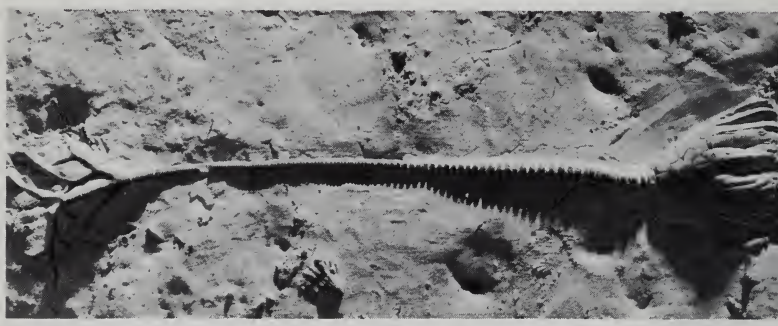
To start with, these primitive plants, exactly as would have been the case with the first land animals, were tied closely to the water. But in time they, too, advanced inland, developing roots with which they could anchor themselves in the soil and which enabled them to extract water from it. Their stems would have stiffened to hold themselves erect, and this stiffening of their structure would have enabled them to grow larger.

One point that should be made here is that before the land could support an animal population it first must have developed plant cover. For all animal life is based upon plants. Even those that live by preying on their fellow creatures still are plant-supported: the very flesh they eat is derived from plants.

These plants and animals, which in the Silurian period came out upon the land, were the hardy pioneers, the forms of life which had been touched by the wand of evolution. Most Silurian life remained in the comfort of the water.

Mild climatic conditions continued through the period. Lime-secreting organisms which helped to form the limestone of the time swarmed in countless numbers in the seas and into latitudes which today would be much too cold for them. Even the warmth-loving corals throve close to the polar regions.

Fossil Crinoid (upper) and fossil Sea Scorpion (lower).



In the Late Silurian, however, a sharp reduction of the seas ended the favorable environment in which many of the shallow-water invertebrates had flourished for so long. By the time this happened, the trilobites had passed their prime. Silurian species of this ancient animal number less than half those found in the Ordovician period. And the trilobites, as often is the case with a declining life form, had begun to show erratic evolutionary tendencies, developing spines and other ornamentation. The spines may have been defensive, for as the millennia brought new and more ferocious predators upon the scene, the life of the trilobite must have become increasingly insecure. In other instances, there seems to have been no reason for the fantastic ornamentation which some of the trilobites developed. Undoubtedly there was a purpose, for there always seems to be a purpose and a reason for everything that happens. But if there were, it was not too effective, for in a few more million years the trilobites, along with many other life forms of this summer world, would become extinct.

The graptolites also were on the decline in North America, but continued to flourish in Europe.

Corals and brachiopods increased greatly in number during the Silurian, and the crinoids thrived. On the shallow sea floors of Illinois and Wisconsin, and in many other places, they formed extensive gardens of living animals, waving like flowery plumes in the water. More than 300 species of crinoids have been found in Silurian rocks.

Sea scorpions (the eurypterids) reached the climax of their development in the period. Large-headed animals, their bodies terminated in a spine or flexible tail. The head bore six pairs of appendages. In some cases the first pair bore pincers; the last pair often were modified to be used as swimming paddles. Most of the sea scorpions were no longer than a foot, but the largest known form was nine feet—a most ferocious prowler of the water. While no one can be certain, there is some reason

EARLY SILURIAN

to believe this largest of the scorpions was a fresh-water rather than a sea inhabitant.

The Silurian period began 425 million years ago and continued for about 20 million years. It is divided into three epochs, the Early (or the Medinan, or the Alexandrian), the Middle or Niagaran, and the Late, or Cayugan, the last named for outcrops near Cayuga Lake. The specific geographic names here assigned the epochs are valid only in North America.

As the period opened in North America, the mountains in Appalachia stood high and rugged. The rest of the continent still was flat, a land of plains or gently rolling hills.

The sea crept into the Appalachian geosyncline from the

south, and before the end of the Early Silurian extended north almost to the present Great Lakes region and west to Oklahoma and central Texas. Meanwhile another sea pushed in from the northeast, covering a good part of southeastern Canada and almost, but not quite, linking with the southern sea. Apparently some sort of land barrier kept the two bodies of water separate during the entire period. This can be deduced from the fact that fossils in the two areas covered by the respective seas differ in some respects, showing that two distinct faunas existed almost side by side. If the two seas had ever been united, even for a short time, the two faunas would have mixed, migrating from one sea to the other.

In the southern sea sediments from Appalachia spread as far west as the Cincinnati Arch, the force of the rushing torrents which poured down from the towering mountains carrying their heavy loads of debris far into the sea. The Cincinnati Arch stood as a dividing line between the eastern and the western sectors of the southern sea. Much of the debris carried down off the highlands of the Taconic Mountains was composed of sand and gravel. This layer of sediments was compacted into the Medina sandstone. Under varying local names, it extends from New York to Alabama. The Medina is an extremely hard stone, harder than the usual sandstone, which in many instances tends to be soft. Many conspicuous ridges in the present-day Appalachians are composed of it. The famous Delaware Water Gap is cut through Medina sandstone.

West of the Cincinnati Arch the clear water of the sea swarmed with lime-secreting organisms (which are partial to clear rather than to roiled and muddy water), busily laying down massive layers of limestone.

During this time the western part of the continent must have stood slightly higher than the east, or it may have been rising slightly. There is little evidence that during the Early Silurian any great part of it was ever under water. A sea seems

to have moved briefly into the Cordilleran geosyncline, covering part of California and extending northward into Nevada and Idaho. But this invasion was of short duration.

During the Early Silurian, massive erosion was at work in Appalachia, wearing down the mountains. Toward the end of the epoch, the sea withdrew briefly from the continent. When it came back again at the beginning of the Middle Silurian, Appalachia may have been reduced to a level plain. Instead of sands and gravel, the streams from that ancient land carried little except mud into the sea. Gone were the brawling streams whipping down the mountain gorges; in their place, apparently, were slow and sluggish rivers. The mud which these rivers carried formed the Clinton shales which are found in the Appalachian area and western New York, and curiously enough, in Wisconsin. While Clinton here is applied to shale, it actually is a series designation, and grouped under it are shales and sandstones, and some limestones.

During the Middle Silurian, the epicontinental sea spread over nearly half of North America. Spilling out of the Appalachian geosyncline, the sea crossed southern and western Canada, reaching Alaska and the Arctic Ocean at the time of its greatest extent.

In the west the waters of the Cordilleran geosyncline extended from southern California north to Idaho and east into New Mexico and Texas.

The extent of the seas during the Middle Silurian was almost as great as in Ordovician times. All coastlines everywhere in North America appear to have been low. Little sediment other than fine mud was poured into the extensive seas by the sluggish rivers. And in the absence of land sediments, the waters of the sea were sparkling clear. In the areas covered by this great sheet of clear water, thick beds of limestone were laid down.

Niagara Falls flows over the Lockport limestone of the

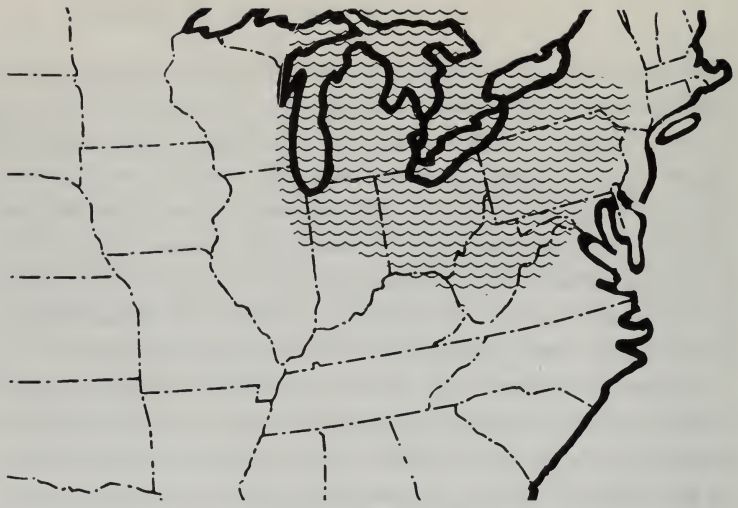
Middle Ordovician, cutting away the softer Clinton shale which lies beneath the limestone. Beneath the Clinton shale are the earlier Medina sandstone and the Queenston shale, both of which also are softer than the limestone. As the water action cuts away the softer stone, the limestone is undermined and periodically large blocks of it break off, tumbling down into the gorge. Thus Niagara Falls moves steadily, and rather rapidly, upstream. A few thousand years from now there will be no falls, but simply the gorge which the river has cut.

There is evidence that during the Middle Silurian severe volcanic action took place in Maine, Nova Scotia, and New Brunswick. In certain localities in these areas lava accumulated to the depth of several thousand feet. But this seems to have been an isolated and a local activity; throughout its entire 20 million years the Silurian was quiet in North America.

At the end of the Middle Silurian the seas withdrew from the continent again, and in the eastern and northeastern sections of the United States desert conditions developed. The evidence seems to say that the withdrawal of the seas was caused, not by any change in the world's oceanic level, but by a gentle uplift of the land.

An arm of the eastern sea, trapped by the rising of the land, became a large salt lake that reached, at its greatest extent, from Wisconsin eastward to central New York. This body of water, known as the Salina sea, covered the present basin of the Great Lakes, with the sole exception of Lake Superior.

During its thousands of years of existence, it deposited huge beds of salt and gypsum—far too much of each to be accounted for by a single salt lake. Geologists believe that the arm of the ocean, when first cut off, became a dead sea. Evaporation of the water, reducing the volume of the water, caused the sea to deposit a large part of the salt held in solution—there simply was not enough water, after evaporation, to hold all the salt in solution. Later the connection between this inland



THE SALINA SEA

sea and the ocean was re-established and salt water flowed in once again. Once more the inland sea was cut off, once again the trapped water evaporated and more salt was deposited. This may have happened time and time again, resulting in salt deposits hundreds of feet thick.

Near Tully, New York, a modern well penetrated 325 feet of salt. In southern Michigan the beds are, in some instances, more than 600 feet thick. For years these deposits have been mined for commercial salt, either by regular mining methods or by pumping water down into the salt-bearing beds, then pumping out the resultant brine and extracting the salt.

Desert conditions appear to have been associated with this mighty salt lake, extending outward for miles around it.

The Silurian period closed quietly in North America, but in west and northwest Europe a great orogeny took place—the Caledonian disturbance. A great mountain range was heaved up, running from Britain across the North Sea, up the western coast of Norway and continuing in a sweeping curve to Spitsbergen and northern Greenland. It is entirely possible that these

ancient Caledonian mountains, extending in a northern arc over a distance of 4,000 miles or more, may have formed a land bridge between Europe and North America. The Icelandic sill, which forms an underwater boundary between the North Atlantic and the Arctic Ocean, may be the roots of that primordial range.

At the same time mountains also formed in France and southern Germany and there is geological evidence, dating from the Late Silurian, of strong rock folding in the Irkutsk Basin of Siberia and in North Africa.

Except for the latter part of the period, when the mountain-building took place, nearly all of Europe was covered by epicontinental seas during the Silurian period. Apparently the water surged in with the opening of the period and did not withdraw until the time of the Caledonian disturbance. At its greatest extent, the sea covered all of Europe except southwestern France, part of Italy, and northern Scandinavia.

Three sea basins can be distinguished—the British, the Central European, and the Western Mediterranean. In all of these basins small islands extended above the water, but the rest of the land was flooded.

In the Middle Silurian, the water made new advances. Much of Poland, nearly all of Italy, and all of the Balkan peninsula lay beneath the water. A channel of this sea, running through southern Russia, connected with another epicontinental sheet of water lying in the Great Basin of central Asia.

As the period came to a close and mountains reared up in the north, the water drained off a great part of the continent, but in the south the sea persisted into the next period, the Devonian.

In Asia an extensive sea lay in the center of the continent. Limestone strata in northern Siberia and on some of the Arctic islands north of the continent give evidence of the sea. Some Silurian rocks also are found in the Himalaya mountains.

Silurian rock is found only in the north of Africa, where the Mediterranean basin extended over the rim of the continent. Glaciation took place in the southern part of the continent toward the end of the Silurian, or perhaps at the beginning of the Devonian. The Table Mountain sandstones include traces of tillite, non-sorted, non-stratified sediment carried or deposited by glaciers. Striated boulders, their surfaces scarred by the scraping and grinding of great mountains of ice, are embedded in the tillite.

Sometime during the Silurian a mountain range, running north and south, existed in the central Sahara.

In Australia both limestones and sandstones date back to the Silurian period, and in South America beds of Silurian rock are widely distributed in the Amazon valley where strangely enough, neither Cambrian or Ordovician rocks have been found. Other Silurian rocks are located in the Andes, particularly in Peru and the high plateau of Bolivia.

The most dramatic geological feature of the Silurian period undoubtedly are the Caledonian mountains. They reared up at the end of the period in the greatest mountain-building upheaval Europe has ever known. Towering as high as, or higher than, the Alps, they may have extended around the rim of the polar regions into Alaska.

But the most significant happening was no mountain, but the fragile life, both plant and animal, that crept out of the sea and lived for a time upon the fringe of the friendly water while it gathered strength to advance upon the land.

For the first time life had definitely forsaken the sea and now lived upon the land. As a milestone in the history of the earth, this was second only to the appearance of life itself upon our youthful planet.

9. THE DEVONIAN

The Fish That Walked

THE DEVONIAN PERIOD often is called the Age of Fishes. There is more significance in that designation than is apparent at first glance, for it was in the Devonian period that a primitive lungfish traded fins for legs and became the first vertebrate to walk upon the land.

The fishes, for the first time, show a great increase in number and a rapid evolutionary development in the Devonian. Prior to this there is only one known fish, the ostracoderm, which first appeared in the Ordovician.

The ostracoderms still continued in the Devonian, but stayed rather small, six to eight inches in length. They generally lived in rivers, although some of them may have ventured into the sea.

The placoderms of the Devonian show a marked evolutionary trend over the ostracoderms. They developed jaws and in some cases had paired fins. Some apparently left the river for the sea. One sea-going species reached a length of 20 feet or more. Only a few of them survived the Devonian.

The earliest fossils of the shark, a fish family which has survived into the present day, are found in the Devonian rocks

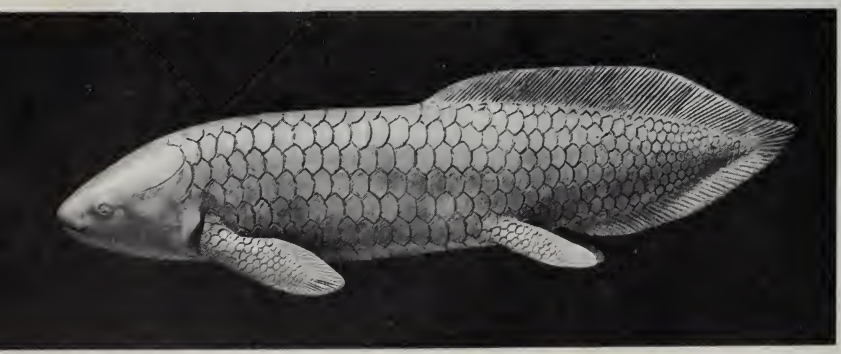
of North America. Two different forms were present in the period—the sharp-toothed shark and the flat-toothed, the flat teeth for the crushing of shells. Most of our modern sharks have sharp teeth, although a few of the shell-crushers still exist.

An important evolutional development, the appearance of bony fish, also traces back to the Devonian. These fish, however, were extremely primitive in their structure; the bony fish we know today did not develop until the Jurassic period 165 million years or so after the Devonian. The bony fish of the Devonian did not boast an entire skeleton of bone—in part gristle took the place of bone.

These so-called bony fish, the crossopterygians, bore heavy scales and had thick-lobed fins and were divided, even back in Devonian times, into three groups. All of them had heavy bodies, and in appearance must have been very much alike. However, the swim bladders of two of the groups, the *Rhipidistia* and the *Dipnoi,* had modified into lungs, and a pair of openings in the roof of the mouth, in these two groups, communicated with external nostrils. Thus they had two ways in which they could breathe—through their gills, as does any normal fish, or through their nostrils. These fish are called lungfish.

So far as fishes in general were concerned, the lungfishes were only a sideline of the main evolutionary line. Today the last of the lungfishes are dying out, and insofar as the fish family is concerned the business of breathing through the nostrils was an evolutionary failure.

Restoration of primitive lungfish.



But while they may have been a family failure, they were the key to the development of a higher life on earth. It is believed that the *Rhipidistia,* one of the groups of lungfish, are the common ancestors of all higher vertebrates. In the course of the Devonian some of the lungfish evolved into amphibians.

Some of the lungfish may have lived in a pool of fresh water. The pool, in the course of drying up, became stagnant. Most of the other fish would have died from the lack of oxygen, but the lungfish, able to go to the top of the water to breathe when necessary, were able to survive until the rains came and the pool once more was filled and the oxygen replenished. Through successive centuries of the pool almost drying up, these lungfish and their descendants became more and more adapted to breathing through their nostrils. What had started out as an evolutionary sideline had high survival value.

There may have come a time when the food supply in the pool had dwindled and, being able to breathe the air for a short time, the lungfish (which by this time may have evolved into something other than ordinary lungfish) could make short forays by night, when the sun was down, out into the surrounding land to forage for their food, using their strong, and rather large, fins to propel themselves awkwardly about.

Through successive generations, the former lungfish would have further developed their ability to breathe the air, and after a time their strong, muscular fins developed (from forays on the land) into stubby legs and feet.

There may have come a time when the old home pool dried up in some unrecorded drought. And when that happened, the former lungfish (or at least some of them) could have migrated to another and a better pool, walking on their stubby legs and breathing ordinary air.

By this time we probably wouldn't have called them lungfish any more, but amphibians.

For a long time, more than likely, the amphibians stayed in or near the water. Like the frog and salamander today they were not as yet entirely creatures of the land. Most of them never would be. They could, however, live either on the land or in the water. They were at home in either.

But although they were not free of the water, still they were the first vertebrates to walk upon dry land. They were the forerunners of a lot of other things that were to walk on land.

Much of what is written here, of course, must be supposition, for no one can say for certain that it really happened. But it is an extremely educated supposition, backed by evidence.

The skullbones of the Devonian crossopterygians are very similar to the same bones in an amphibian—not in general, but in detail. Essentially the same bones are in the roof of the skull of the amphibian and the skull of the primitive crossopterygian, and the arrangement and the relative position of those bones are very much alike. Even modern amphibians betray a close relationship to fish. They cling throughout their lives to a watery environment. Frogs lay their eggs in water and the tadpoles have a distinct resemblance to fish. Even in its adult stage, a frog must stay near the water, for to retain health its skin must be moist.

There is no direct evidence of amphibians in the Devonian rocks. What may be an amphibian footprint has been found in Devonian rock near Warren, Pennsylvania, but there is no other evidence. But in the next period, the Mississippian, unmistakable amphibian footprints have been found, and a few skeletal remains as well. There is little question in the minds of most palentologists that primitive amphibians did exist in the Devonian, and that they did evolve as described above.

It was the *Rhipidistia* group of crossopterygians that evolved into amphibians. There was, you may remember, an-

other group called *Dipnoi,* which also had developed lungs and nostrils. This group evolved into nothing—they remained as lungfish. And while *Rhipidistia* disappeared into another form of life, *Dipnoi* kept right on being lungfish. The last of them are still alive today in the rivers of Africa, Australia, and Brazil.

The African lungfish, *Protopterus,* ranges from the White Nile to Lake Tanganyika and the Zambesi river. It has vestigial gills which are inadequate to supply sufficient oxygen and, as a result, it must come to the surface periodically and fill its lungs with air. During the summer, when the water becomes stagnant or, if the fish lives in a pool, may disappear entirely, it burrows into the mud. Some of the slimy excretion which covers its body dries and forms a tough envelope to enclose the fish. It can remain like this for months, riding out a dry season or a drought, breathing air through its nostrils and living on the fat stored in its body. When the rains come again, the mud softens and the fish comes to life. While it is in its burrow of mud, its bodily processes are slowed, requiring less food and oxygen. It exists in a state of suspended animation called estivation.

Another lungfish, *Lepidosirin,* lives in the Amazon basin, its way of life very similar to that of the African lungfish. *Epiceratodus,* the Australian lungfish, possesses no gills and must rely entirely upon its ability to breathe air. Periodically it rises to the surface to exhale, then refill its lungs with air.

Other than for the lungfish, the crossopterygians were thought, until recently, to have been extinct. There was no fossil evidence of them in rocks later than the Mesozoic era, and it was believed they had died out during that time, before the dawn of the Cenozoic.

Then, in 1939, a living specimen was hauled out of the sea by a fisherman off East London, South Africa. This is the famous coelacanth, which is descended from the third group

Caught off the coast of Madagascar in 1953, this coelacanth was the first intact specimen to be studied by scientists.

of the primitive crossopterygians. The finding of the fish created a worldwide furore. It was hailed by newspapers as a living fossil. It was no such thing, of course. It was simply an ancient form of life which had existed into the present quite naturally and unobtrusively.

The coelacanth netted in 1939 showed remarkably little evolutionary change from the fossils of its far ancestors found in primitive rocks. About five feet long, it had the same heavy fin lobes of the crossopterygians of millions of years ago.

Since 1939 a dozen or so coelacanths have been caught and studied by scientists, and it now develops that for years the natives of the Comoro islands have been catching and eating them, relishing their extremely oily flesh.

Other newcomers in the Devonian were the insects. Before the period ended there were many different species, the ancestors of the hordes of insects that we know today. Spiders also put in their first appearance.

And along with the insects came a new evolutionary invention—flight.

Biologists believe that insects developed flying ability within a relatively short time after their appearance.

One theory advanced to account for the development of the wings used in flight is that the flying insect developed from a leaping insect which evolved a special set of muscles to operate the legs that controlled the long glides resulting from its leaps. These muscles, it is suggested, developed into wings.

This theory, however, is not too satisfactory.

A new theory, recently suggested by a British scientist, Dr. V. B. Wigglesworth of Cambridge University, is that the wings arose from small expansions of the insect's anatomy in the region of the thorax, which would have facilitated takeoff in a strong wind.

Dr. Wigglesworth points out that all evolutionary developments (of which wings would be an example) do not develop unless the first rudimentary evidences of them have a "selective" value which makes their possessor better able to survive.

If these rudimentary characteristics do have survival value, then they are further developed to a greater value. In other words, an insect could not have developed wings unless the characteristic which in time was to develop into wings had some value from its early beginning.

Many wingless insects today still get around in the air. The insect body structure is so light that any strong wind will lift it and carry it for great distances. Insects which have been blown along by the wind have been captured at heights of up to 5,000 feet.

Dr. Wigglesworth suggests that this tendency of the winds to carry insects for great distances did have a "selective" value in introducing insects to new areas of the earth's surface where, for a time, they might be free of natural enemies and could develop more rapidly.

Devonian forest.

It is his belief that small body expansions in the thorax region of some insects may have been of some aid in being picked up by the wind. That is, an insect which had such an expansion or projection may have had a better chance of being picked up and wafted about by the wind than an insect that didn't have it.

Given this premise, it is logical to speculate, says Wigglesworth, that muscles would have been developed to manipulate these plane surfaces, thus increasing their efficiency in takeoff in a high wind, perhaps even affording some control of the insect's body during landing.

Once these short, small steps were taken, then it would only take time and further evolutionary processes to develop wings which would make the insect independent of the wind.

In the Devonian fish learned to walk and became amphi-

bians, and insects developed wings to become the world's first flying creatures. And one thing more—in the Devonian also appeared the first forests the world had ever known.

These were weird forests, unlike any forest upon the earth today. For the most part they were made up of ferns and tree ferns. Sprinkled among the ferns were trees called lycopods, covered by overlapping leaf-like scales—thus often called scale trees. In places there would have been rank growths of primitive horsetails which in later ages would grow to imposing size. None of the trees or the plants of the Devonian had true leaves. Nor did they have any kind of flowers. Most of the trees bore spores, but before the period ended some of the ferns had developed seeds. (A spore is a single cell from which a new plant may grow. A seed is a reproductive cell enclosed in a protective envelope which also may carry a supply of food on which the cell can start its growth.)

Some of the tree ferns in these primitive forests left fossilized trunks measuring three feet in diameter. Some of the scale trees grew to a height of 40 feet.

Many plants probably had existed in the Silurian period, but because of the lack of tough and woody parts had left behind no fossils. We do know that by the Middle Devonian much of the earth probably was covered by some sort of vegetation.

The earth, in this period, which began about 400 million years ago, was beginning to assume some of the aspects which today are familiar to us. No longer an empty place of rock and water, its face now was clothed in green. Ambling things moved upon its surface, and flying things rode its air. Still strange to modern eyes, it would nonetheless have been a less foreboding place than it had ever been before.

In North America the Devonian period succeeded the Silurian with no sharp break.

In the Early Devonian the sea entered the St. Lawrence

valley and crept down the Appalachian trough to the Gulf of Mexico, isolating Appalachia from the rest of the continent. Extending out from the southern end of the geosyncline was an embayment which reached as far as southern Oklahoma. On the northern edge of the continent shallow seas covered some of the present Arctic islands and flowed down over the northern part of the land now occupied by Hudson's Bay.

Appalachia must have been flat at this time. The invading sea in the early part of the Devonian laid down the Helderberg limestone almost up to the western coast of Appalachia, indicat-

EARLY DEVONIAN

ing that the clear water of the sea was scarcely muddied by sediments flowing off the land.

The Helderberg limestone, in many places, is overlain by the Oriskany sandstone, which is largely composed of pure quartz sand. The sediment which makes up this stratum must have come from the erosion off a sandy plain.

No retreat of the sea is apparent to mark a boundary between the Early and the Middle Devonian. Rather, the eastern sea spread into the Upper Mississippi valley, while in the west both Canada and the United States were invaded by a sea which surged southward from the Arctic Ocean and northward from southern California, along the Cordilleran geosyncline.

In the initial phases of the Middle Devonian, Appalachia must have remained low, for the Onondaga limestone, unmarred by land sediments, stretches all across the east and westward into Oklahoma. Later in the epoch, however, muds pouring into the eastern edge of the Appalachian geosyncline laid down the dark Hamilton shale. This shale contains fossils of land plants and fresh-water animals and indicates that the eastern land mass was rising rapidly.

Muds and sand continued to stream into the eastern edge of the sea throughout all the rest of the period, signalizing the continued uplift of Appalachia. This upheaval culminated in what is known as the Acadian disturbance. During the course of this orogeny the northern end of the Appalachian geosyncline was raised permanently above sea level. Never again would an invading sea extend all the way across the eastern edge of North America.

The Acadian mountains rose from eastern Canada in the north as far south as the Carolinas. In New England and Canada considerable igneous activity was associated with the uplift. Mount Katahdin in Maine is an exposed granite batholith that rose at that time from deep beneath the crust. Today it stands as a mass of rock almost a mile high in the midst of flat

terrain. Another Devonian batholith in New Hampshire forms the core of the White Mountains.

As the Acadian mountains grew, the sediments washing off their mighty slopes formed the Catskill delta, which was about 100 miles wide. The sediments deposited in the delta and the alluvial plain that formed behind it reached a maximum thickness of 13,000 feet. Erosion later carved the Catskill Mountains out of it.

During the latter part of the period volcanoes were active, not only in New England, and southern Canada, but in southern Alaska, western British Columbia, and northwestern California.

Early in the period a long narrow arch, a geanticline, began to rise in the west almost exactly down the middle of the Cordilleran geosyncline, splitting the depression into two troughs. The arch, known as the Cordilleran geanticline, extended from southern Alaska, through British Columbia and across Nevada into southeastern California. At times the arch may have been covered by a very shallow sea as the waters in the two troughs rose to cover it. At other times it stood above the water and deposited sediments into both the eastern, or Rocky Mountain, trough, and the western, or Pacific, trough. The two troughs, because of the weight of the sediments which were continually being added, continued to sink slowly on both sides of the geanticline.

The Devonian was the period which saw the formation of the famous Old Red Sandstone in Europe, and particularly in England and Scotland. The formation became well known many years ago, due to a classic text, *The Old Red Sandstone,* written by Hugh Miller from his study of the stone quarries near Cromarty, Scotland.

The Old Red Sandstone is a continental rather than a marine deposit, being laid down in a number of basins between the ranges of the ancient Caledonian mountains. Most of the

Middle Devonian sea bottom.

sediments which form the stone appear to have been deposited by streams, which dropped their heavy loads of sediments from the mountainous highlands as they flowed over broad alluvial plains. There is evidence, as well, that some parts of the deposit were laid down by the wind. Much of the deposit is red in color, but intermixed are grayish sandstones and shales. No salt or gypsum is present, which indicates that all deposits were laid down under humid conditions. The red color of the sandstone comes from the oxidation of the sediments as they lay exposed to the air on the alluvial plains. Some of the shales plainly show mud cracks, which occurred when the mud of which the shale is formed was exposed to the baking sun.

Apparently the formation as a whole was laid down during a period of alternating drought and heavy rainfall. The gray beds which are interspersed with the red relate back to the time of heavy rainfall, when the sediments were quickly covered and not exposed to the oxidation occasioned by the air.

Interbedded with the sandstone and shale are thick layers

of volcanic tuffs (stratified rocks) and lava, bearing testimony to periodic outbreaks of volcanism in the mountain chain.

Few fossils are found in the strata. The few which are found are of land plants, fresh-water fish, and some sea scorpions which apparently had adapted to fresh water.

The Old Red Sandstone also occurs in the Baltic area and on the island of Spitsbergen. The Caledonian mountains, in their great northwestward arc, ran across these areas. Here in these famous old red beds, we have dramatic evidence of a mighty chain of mountains wearing down and slowly being leveled over a span of time covering millions of years.

The Caledonians certainly stood above the water for all of the Devonian. North central Asia also was dry land, and so was part of China. But south of these dry lands lay an extensive sea that spread across Europe and Asia, from the Atlantic to the Pacific. All of southern Europe was covered by its waters, and in the Middle Devonian an embayment of the sea reached northward toward the highlands of the Baltic, to almost cut Europe and Asia apart.

A good part of India and perhaps most of the Malay peninsula were under water. Africa was sliced off, top and bottom, by the seas. South America was almost completely under water during much of the period. The highlands of Guiana and Brazil were islands. There is some belief that the Andean coastal strip may have been a long, narrow peninsula of the Antartic continent, extending northward for hundreds of miles; it, too, may have been above water. Australia was cut in half, its eastern half covered by the sea.

Elsewhere the Devonian was a time of widely-spreading seas, but in North America the water did not cover as much area as it had in previous periods. At its greatest extent, during the Middle Devonian, the North American sea covered nearly 40 percent of the continent, but at the close of the period it withdrew and the land once more stood dry.

10. THE MISSISSIPPIAN

The Day of the Waddling Beasts

NOW THERE WERE creatures that walked the land—awkward, waddling things that in ages yet to come would give rise to the terrible tribes of reptiles that would fill the world with fear and the thunder of their tread. But in the Mississippian these shambling creatures—the amphibians—were lazy, blundering animals that spent their lives sprawling near the water, from which, by slow degrees, some of them would divorce themselves and in time become true denizens of the land.

Arising in the Devonian, these primitive amphibia persisted for at least a hundred million years, finally dying out in the Triassic period of the Mesozoic era. They ranged in size from a few inches long to 15 feet. Some of them, throughout their history, retained the elongated, fish-like body with a flattened tail. Others developed into stubby, toad-like forms.

It appears that it was the smaller amphibian which was the most adaptable and thus the most successful in developing a way of life that freed it from its dependence on the water. As we shall see, this independence of the water played a great part in the evolution of the reptiles, which took over domination of the earth in the Mesozoic era.

As the Mississippian dawned, the amphibians were well established and in the following period, the Pennsylvanian, they became the unquestionably dominant form of life on earth.

If one were to assign a dominant form of life to the Mississippian, however, the crinoids would have to be given top consideration. These animals that looked like plants grew in such rank profusion in the shallow seas that their fossils, embedded in crinoidal limestone, can be found over wide areas. In no other geologic system has such a variety or number of well-preserved crinoid fossils been discovered.

Sea urchins also were abundant. Many melon-shaped urchins, called echinoids, are found in the St. Louis limestone laid down in the Mississippian period. Brachiopods still were common, but the trilobites, which had swarmed the earlier seas in countless numbers, were almost extinct.

Fish probably were still abundant, but they did not leave behind them as many fossils as they had in the Devonian. The great armored arthrodires, which had developed as the terrors of the Devonian seas, became extinct during the Mississippian. The lungfish had passed their heyday. Best recorded Mississippian fish are the shell-crusher sharks, which had blunt teeth for the crushing of shellfish. Some 300 species of this kind of shark are known from the Mississippian. A few still exist today, the best known of which is the Port Jackson shark of Australia.

The Mississipian and the Pennsylvanian are recognized as distinct geological periods only in the United States. In Europe the two periods are still combined in one period, the Carboniferous, but with the period divided into the Lower and the Upper Carboniferous.

The Mississippian began about 345 million years ago and continued for about 35 million years. The Pennsylvanian is generally considered to have begun about 310 million years ago, but the division between the two is somewhat hazy.

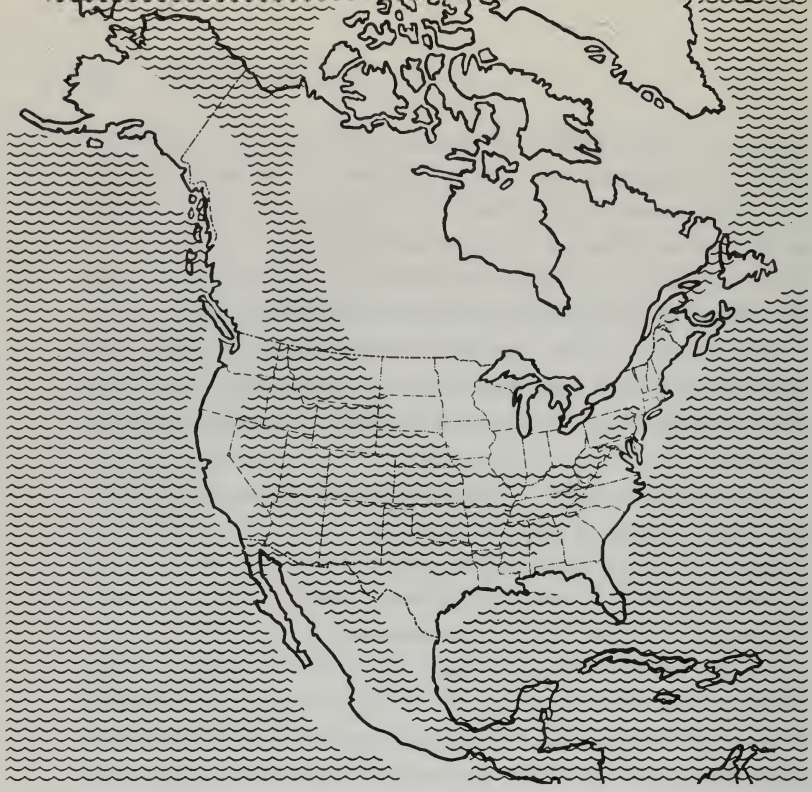
As the Mississippian opened in North America, Appalachia still was a highland and in New England the massive Acadian mountain ranges still towered into the sky, effectively cutting off the northern half of the Appalachian geosyncline. But south of the Acadians the trough still persisted, slowly sinking beneath the weight of sediments which came sluicing down into it.

The interior of the continent was still low, as it had been since the dawn of geological history—still a level land with gently rolling hills, standing just a few feet above the normal level of the sea.

Llanoria, the ancient land to the south, was above water and rising. In fact, at some time during the period the highlands of Appalachia and Llanoria may have been connected, forming a sweep of high, if not mountainous, land around the entire eastern and southern edge of the continent.

At the end of the Devonian, North America had emerged as the waters drained away, but now the seas came creeping in again, following the old familiar path up the Appalachian geosyncline and spreading out until they covered a large part of the present Mississippi valley, finally joining with a second sea which had inundated the continent from the west. This extensive interior sea persisted for the greater part of the period.

In the west the sea extended from southern California to the Arctic Ocean. Cascadia stood as a separate land, isolated from the mainland by the sheet of water which filled the Cordilleran geosyncline. Early in the period the Mexican trough, actually an arm of the Cordilleran geosyncline, extended from the southern end of the geosyncline to the Gulf of Mexico, making Llanoria an island. The Canadian Shield and some of the land immediately south and west of it stood above the water, but the rest of interior North America was covered by the shallow sea. Essentially, the continent was divided into four large islands—Appalachia, Llanoria, Cascadia, and the Cana-



dian Shield, with some other smaller islands, such as the Ozark Dome and the Cincinnati Arch, scattered in the sea.

Throughout much of the continent, the sea lay down thick layers of limestone, but in the areas adjacent to the lands sediments carried by the rivers formed shales and sandstones. Along the shores of Appalachia, in particular, a great deal of sediment came down off the mountainous slopes and was deposited in a wide sheet to the west. The mud and sand was carried as far west as Indiana, Kentucky, and Tennessee, forming the Pocono sandstone. In many places this massive outpouring of sediments built far-reaching coastal plains which extended out from the western shores of Appalachia.

While the general climate appears to have been too damp to allow any oxidation of the muds spread across these coastal plains, there is some evidence of arid conditions during the early part of the period in southern Michigan, Ohio, parts of Virginia and West Virginia, Nova Scotia and Newfoundland. Here beds of salt and gypsum are found, probably formed in lagoons reaching back from the sea. It is possible that the Acadian mountains may have influenced the weather to bring about such pockets of aridity.

In the Mississippi valley area, where the sea lay clear, unmuddied by the sediments coming in from the bordering highlands, vast systems of limestone were laid down. Altogether, they range from 2,000 to 2,500 feet thick. Uniform sheets of these various limestones extend from Iowa to central Kentucky and varying distances north and south.

The first layer is the Kinderhookian series, deposited when the early sea still was fairly small and thus less widespread than the succeeding series. In a number of places this limestone shows the intrusion of debris from adjacent land masses.

The next series, the Osagian, covers a larger area. The seas now were clearer and there is less land debris.

The Meramec series is composed of great thick layers of stone, In Indiana this stone is extensively quarried. Soft and uniform in texture, it is easily tooled, and is used as facing for many buildings.

The St. Louis limestone is the most extensive of all the layers from the Mississippian. It forms the bold bluffs along the Mississippi river near St. Louis and stretches in a more or less continuous sheet from Iowa to Alabama. The Ste. Genevieve limestone lies above the St. Louis. In the ages after its formation, it was subjected to much action by underground water. Mammoth Cave and many other caves in Kentucky have been carved out of the St. Genevieve limestone.

The Chester series, formed of alternating sandstones, shales,

and limestones, belong to the final days of the period and represent the spread of sand and mud into the sea covering the Mississippi basin following the uplift of Appalachia and Llanoria.

This uplift came in the Late Mississippian and it was during this time that the simultaneous rising of the two land masses may have resulted in a rim of highlands being elevated around the entire eastern and southern coasts of the continent, hemming in the inland sea.

Both of the land masses seem to have risen to considerable height. Debris and sediments from Llanoria flooded northward into the Ouachita trough, while in the east Appalachia's deposits laid down those formations known as the Mauch Chunk beds. Conditions of great dryness, or at least of only seasonal rainfall, are indicated in the beds. Extensive redbeds have been formed, due to oxidation during extended dry periods. The rock layers are made up of dull red sandstone alternating with bright red shales and siltstones. The Mauch Chunk rocks also show mud cracks and raindrop impressions such as are found in the shale of Europe's Old Red Sandstone.

Amphibian tracks and some skeletal remains also are found in the beds. It is believed likely that the amphibians lived in the mud holes of the barren flats of the broad coastal plains. Many of these pools must have dried up during the extended dry spells, and in imagination one can envision the amphibians leaving their tracks behind them as they sought to find another pool after the old home puddle dried up and vanished.

In the southwest, the deposits from Llanoria built up a vast delta reaching out into the Ouachita trough. The rocks, mostly sandstone and shale, may have a depth of up to 12,000 feet. They are now covered in large part by limestone laid down during the following period, but outcrops of them appear here and there.

Included in these beds are at least five separate layers of

volcanic ash, evidence of recurring periods of volcanism which accompanied the uplift of the mountains to the south. One of these layers is 85 feet thick. There can be no conclusion other than that the ash was carried northward by winds from the belching volcanoes of Llanoria.

As the period came to a close some folding of rocks apparently took place in the Ouachita trough, in present-day Arkansas and Oklahoma, the forerunning tremors of mountains yet to come. Much the same thing happened as well in Colorado and Wyoming. And in the east the now old Acadian mountains may have risen anew to gain a few more million years of existence.

11. THE PENNSYLVANIAN

Coal and Cockroaches

In the Pennsylvanian period a set of special conditions of climate and geography resulted in the forming of the major coal beds of the world. Some minor coal deposits had been formed in the Mississippian period, and other beds of coal and lignite have been laid down in the periods which came after the Pennsylvanian, but at no time in the history of the earth had so much fossil fuel been tucked away in the rock strata as during this period which began about 310 million years ago and continued for some 30 million years.

The climate at the onset of the Pennsylvanian seems to have been growing steadily warmer and moister, so that tropical or near-tropical conditions finally came to exist over a large part of the world. This sort of climate encouraged the growth of the vast forests which would have been necessary to provide the raw material from which coal is made. The character of the forests also would have had something to do with it—fast-growing vegetation which quickly reached maturity and died to give way to continuing growths.

To form coal, water would have been necessary to protect the fallen vegetation from the air and thus save it from decay,

and this condition was supplied by great swamps which formed in those areas of the world where the largest coal deposits have been found.

At the beginning of the period in North America a mountain rim, brought about by the joining of the highlands of Appalachia and Llanoria, extended from Newfoundland to Alabama and across the Gulf of Mexico into northern Mexico. Because of these highlands, the old pathway of the epicontinental sea, the Appalachian geosyncline, was blocked. But early in the period the sea came flooding in from the west, filling the great basin of the continent's interior. During much of this time the Canadian Shield was the only major part of the low interior which remained above the water.

The sea established itself as a true epicontinental sea, depositing limestone across the western part of the United States as far as the Mississippi basin. But in the eastern part of the continent the sands and muds pouring off the encircling highlands to the east and south, and from the emergent Canadian Shield, acted to block the further advance of the sea. As fast as the eastern interior basins sank, the sediments from the bordering land masses filled them again, and as a result large areas of what is now the eastern United States were transformed into vast swamps which were covered by great forests. These were the famous coal swamps.

For unknown ages the sea and the land fought for supremacy. At times the sea extended as far east as western Pennsylvania. At times the swampy eastern shoreline of Appalachia extended as far west as Kansas and Nebraska. Century after century the shoreline fluctuated back and forth, with the result that the Pennsylvania system of rocks is composed of alternate layers of marine and non-marine deposits. And in many of the non-marine deposits are located coal beds of varying thicknesses.

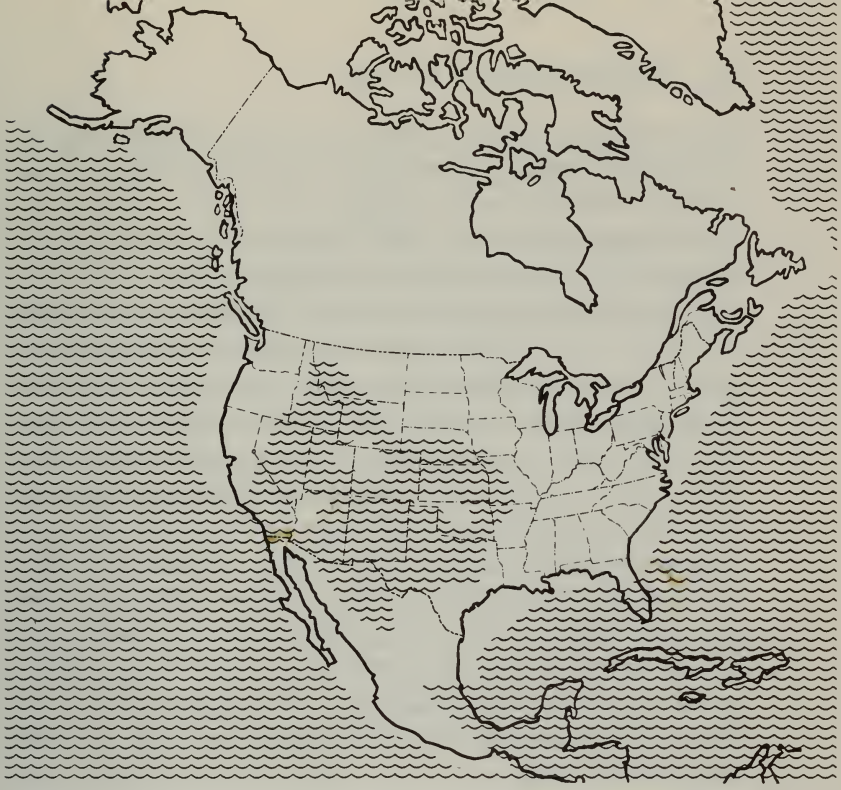
Over much of the western part of the continent, where

the sea lay distant from any land mass, great sheets of limestone were deposited. But in that region north of Llanoria, where the land had started to rise in the Mississippian period and continued to rise in the Pennsylvanian, thick deposits of sediments were washed into the sea. An adjacent highland or mountain area apparently had started to rise either late in the Mississippian or early in the Pennsylvanian in the northeastern corner of New Mexico, and between these mountains and the Colorado mountains synclinal basins were formed, trapping the sediments which flowed down off both the mountain masses and sinking between their weight. Here the Pennsylvanian system of rocks is especially thick.

During the greater part of the Pennsylvanian, perhaps all of it, the Grand Canyon region appears to have been a low island. There is no Pennsylvanian rock in the walls of the great chasm. Rather, the redbeds of the succeeding period, the Permian, lie immediately on top of the limestone laid down by the seas of the Mississipian period. But immediately west of the Grand Canyon area the Pennsylvanian limestone measures half a mile in thickness, evidence that a sea covered that region during the entire extent of the period.

Extremely thick layers of rock were deposited during this period in the eastern half of the United States by sediments washing off the Appalachian highlands and the mountains of Llanoria. The Pennsylvanian rocks are 9,000 feet thick in Alabama. To have supplied this much sediment, both Appalachia and Llanoria must have been continually rising. Otherwise erosion would have worn them flat.

Early in the period a crustal deformation buckled the area to the north of Llanoria, forming a chain of domed mountains along the Panhandle of Texas and the Southern boundary of Oklahoma. The Wichita and Arbuckle mountains of today are the eroded stumps of this ancient chain, and the evidence of it still remains in the buried Amarillo range of the Panhandle.



PENNSYLVANIAN

As the mountains rose out of the sea which then covered the area, synclinal basins formed on both their flanks, trapping the debris which eroded off them. At the same time sediments continued to wash into the Ouachita geosyncline to the south, off Llanoria. It is likely that at times, as well, some sediments from the distant mountains of Appalachia may have reached the region.

The Oklahoma mountains probably did not reach too great a height. They were located in a subsiding area, surrounded by the sea, and the trapped sediments flowing from them into the flanking basins tended to bury them in their own debris.

Two uplifts apparently occurred in the area, one early in

the period, one near the middle of it. It is possible that the Colorado mountains may have been a part of the same general system as the Oklahoma mountains.

In Europe the history of the Carboniferous period was very similar to that of its counterparts in North America.

Early in Carboniferous times the Devonian seas drained off Europe, but within a short time they were followed by another watery invasion which surged high enough to fill many of the closed basins in which the Old Red Sandstone had been laid down. The sea spread from the west of Ireland to central Germany and over the years deposited thick layers of limestone. This layer of limestone is called the Scaur or the Mountain limestone in Britain and the Kohlenkalk in Germany. Six thousand feet thick in England, it thins to some 2,500 feet in Belgium and wedges out just east of the Rhine. In Scotland the Lower Carboniferous is represented by thick layers of sandstone, with a few coal beds interspersed. In southwest Britain and parts of Germany the Lower Carboniferous rock is chiefly sandstone and shale.

Extensive coal beds were laid down in the Upper Carboniferous in Europe, indicating that much the same conditions of climate and geography were present as prevailed in the eastern United States. The coal belt of Wales and southern England extends into Belgium, with a few smaller beds running into France. The Upper Carboniferous coal runs across northern Europe as far east as Poland. The Russian coal beds date almost entirely from the Lower Carboniferous. In Europe the coal-bearing Upper Carboniferous rock strata are known as the Coal Measures.

In southern Europe and northern Africa, Carboniferous deposits are almost entirely marine, the waters of the Mediterranean basin having covered the area through most of the period. This great sea, which had persisisted for millions of years as a feature of the earth's geography, can be traced far to

the east, beyond Europe. It seems to have cut through lower Asia to connect with the Pacific, and arms of it may have run far north into the Arctic regions.

Coal in central Asia, Asia Minor, and Persia seems to date from the Lower Carboniferous, as in Russia. Almost all of the coal found in China, however, dates from the Permian period, which followed the Carboniferous.

At the end of the Lower Carboniferous the Altai, Tian Shan, and Pamir mountains were formed. Late in the Upper Carboniferous some further upthrust seems to have occurred, especially in the Tian Shan region.

In the southern hemisphere the boundary between the Carboniferous and the Permian is not as clearly defined as it is in the north. In Australia and in Bolivia and Argentina in South America there is some glacial evidence. It may be that this evidence is from local mountain glaciers. Or the glaciation may have been general, a forerunner of the widespread ice age which held sway over great parts of the southern hemisphere during Permian times.

Coal is formed when vegetable matter undergoes a slow biochemical change. The change is from raw plant matter to peat to lignite and from lignite to coal. There are two types of coal, bituminous and anthracite. The anthracite results when bituminous coal is subjected to additional pressure, which brings about the release of some of the remaining volatile matter.

Vegetable matter is largely composed of carbon, hydrogen, and oxygen. As the biochemical change takes place much of the hydrogen and oxygen disappears, leaving behind the carbon. It is believed that bacterial action may play some part in the formation of coal, although precisely how has not been determined.

Coal resulted in the great coal swamps when the vegetation died and sank beneath the water, which protected it from decay

Through the centuries huge deposits of muck and peat built up. Some of these deposits may not have turned to coal, but when later sedimentary materials were piled over them, later turning to rock, excessive pressure and heat were generated by the heavy load. Under this pressure and the heat, the muck and peat turned first into lignite and then into coal.

The making of coal would have been slow work, but even at the necessarily slow pace, all the present coal in the Pennsylvania fields can be accounted for over a span of two and a half million years.

It has been estimated that a vigorous growth of vegetation, such as must have flourished in the coal swamps, would produce 100 tons of dried organic matter per acre each century. This amount, compared to the specific gravity of coal, would cover an acre of land less than two thirds of an inch deep. Considering the fact that in the formation of coal four fifths of the organic material would disappear as gases (squeezed out by the pressure of overlying rocks), it would take nearly 10,000 years to deposit a foot of coal. Since the total thickness of the coal beds in the Pennsylvania system is something like 250 feet, the figure of two and a half million years is easily estimated.

This does not mean, of course, that any coal seam in Pennsylvania (or anywhere else in the world) is 250 feet thick. Nor does it mean that for two and a half million years coal was being steadily deposited. Rather, the coal was laid down at different times. Thus the coal seams appear at a number of different levels. About 60 beds in all are known in Pennsylvania, but of these 60, only 10 are thick enough to be mined.

The thickest of these beds is the Pittsburgh coal, which lies in a vein 13 feet in depth. It is known to be workable over an area covering some 6,000 square miles, in western Pennsylvania, eastern Ohio, and northwestern West Virginia. Estimates place the total amount of coal which it originally contained at more than 25 billion tons.

This vein marks the location of a great swamp which maintained itself for thousands upon thousands of years during the Pennsylvanian period, with generation upon uncounted generation of trees and other vegetation sinking into the slimy ooze.

The anthracite field of eastern Pennsylvania, by contrast, covers less than 500 square miles. It represents a part of the vast Appalachian basin which was caught in the folding which came about during the Permian period. Folded by the upheaval of the rocks, the coal over a much larger area was turned into anthracite by the pressure which accompanied the geologic shifting. But in the ages that followed, the greater part of this folded formation was worn away by erosion, which destroyed all coal-bearing formations in eastern Pennsylvania with the exception of some coal which lay in deep folds. The eastern Pennsylvania anthracite field is all that is left of this one-time massive coal field.

One anthracite bed, the Mammoth, which extends through the entire field, has an average thickness of 35 feet and in one place runs to the depth of 114 feet, due to the over-folding of several veins.

That coal was formed from vast forests is evidenced by the fact that the fire clay which underlies the coal in many places still carries the fossil imprints of spreading root systems.

Persistent occurrences of veins of coal in the Pennsylvania area bears testimony to a warm, moist climate which continued over many millions of years. This does not mean, however, that during the Pennsylvanian period the entire earth was subjected to a moist climate. We are fairly sure, in fact, that there were arid regions. Even if we had no evidence we would be fairly sure of it, for during the period there were many high mountains, and lofty mountains mean that the land to the leeward of them is deficient in rainfall—the height of the land operating to keep one slope well watered, the other dry.

Salt deposits in eastern Utah and western Colorado, trace-

able to the Pennsylvanian period, indicate that in the vicinity of the Colorado mountains fairly large areas of aridity may have been the rule.

There is evidence, however, that the climate was warm over a great part of the world, even in the higher latitudes.

The character of the Pennsylvanian vegetation indicates a lack of freezing winters, at least in the lowlands, where we find the fossils of that vegetation, either in the form of coal or in the rocks themselves. The plants—tree ferns, seed ferns, cordaites and scale trees—bore great crops of succulent leaves in a luxurious profusion which today is found only in the tropics.

The leaves were large and their texture bears witness to the fact that they enjoyed rapid growth. The absence of growth rings in the fossil wood indicates that there was no interruption of growth, such as the colder seasons bring about in the forests of our temperate zones. The smoothness and the thickness of the bark is another clue to the rapid growth of these Pennsylvanian trees.

If one wanted, today, to view the nearest thing to a coal swamp, he should visit Dismal swamp in Virginia and North Carolina. Here we have the same situation as existed in Pennsylvanian days, with the exception, of course, that the trees would have been different. In that far-gone age there were no deciduous trees such as we have now—they had not as yet evolved.

A coal swamp would have been a deadly green, unrelieved by any splash of color such as we now expect in any forest. The primitive flowers of the time were small and simple. They carried no color, nor any honey to attract the insects of the time. They had no odor. If we could go back in time to visit a coal swamp, we would find there only the fresh resinous odor we now associate with a conifer forest.

Seed-bearing plants were common by this time, but many

of the trees and other plants still were spore-bearing. At certain times of the year the forests may have assumed a greenish-yellow or brownish tinge, occasioned by the dust of ripening spores. That spores were still abundant is evidenced by the fact that some types of coal (cannel coals, traditionally used in the fireplaces of England) are composed entirely of spore cases.

The only thing in a coal forest which would have been at all familiar to our modern eyes would have been the ferns, but ferns such as are not seen today. Some of these ferns grew to a height of 50 feet and bore fronds five to six feet in length.

Seed ferns, common in the coal swamps, resembled the true ferns in every way except that instead of spores they bore tiny nut-like seeds appended to their fronds. The seed ferns, while they are now extinct, may have given rise to all the higher, seed-bearing plants.

Scouring rushes of giant size grew in the swamps, in impenetrable stands like the cane brakes of pioneer America. Their stems were vertically ribbed and jointed and at each joint they bore a swirl of slender leaves. Some of the stems exceeded a foot in diameter. The stems were not solid, but had a core of pith surrounded by a thick, woody layer seldom more than two inches thick.

Most imposing trees in the forests, and often the most common, were the scale trees. They grew to more than 100 feet in height, with stumps which measured up to six feet across. They are called scale trees because their leaves, close-set against the trunk, left scars in the bark when they fell off, imparting a scaly look to the trunk. The fossil trees look like petrified snake hide.

The scale trees belonged to two well-defined genera—*Lepidodendron* and *Sigillaria*. *Lepidodendron* grew tall and rather slender, branching repeatedly near its top so that it bore a crown of stubby twigs covered with leaves that were slender

Pennsylvanian swamp forest.

and strap-like. Appearing somewhat like overgrown pine needles, the leaves were six to seven inches long and half an inch wide. At the tip of the leaves spore cases were borne in the shape of cones. *Sigillaria* had a thicker trunk. Branches were rare, but near its top the tree bore large blade-like leaves.

Sigillaria had a vertically ribbed trunk, with the leaf scars set in vertical rows. In *Lepidodendron,* however, the leaf scars were arranged in spiral rows around the trunk, and assumed a diamond shape.

About 300 species of scale trees have been identified from fossils, the species about evenly divided between the two genera. Many of the species were large trees, but some were relatively small. All scale trees are characterized by having a fairly thick

pith, covered by two thick layers of cork-like bark. The trees were shallowly rooted. They had no tap root, and the roots were spread out horizontally. Rooted in the mucky swamp, any strong wind would have been apt to topple them.

The other typical trees of the coal swamps were the cordaites. These were the forerunners of our modern conifers, but differed from the pines and other evergreens of today by their needles being blade-like rather than needle-like and in bearing their seeds in racemes rather than in cones. The needles in the different species ran from a few inches to six feet long. The bigger of the cordaites had trunks that measured three feet across, and the tree itself would rear 120 feet into the air. The wood was soft, like our modern conifers, but still maintained a small pith center—apparently a characteristic of the early trees. Branches did not appear except near the top.

Before the end of the Pennsylvanian period true conifers had appeared, but these have been found in only a few localities. It is believed likely that they and other types of more modern trees may have been developing in the uplands during this time. This could have happened without our knowing it, for conditions there would have been less likely to produce fossils than was the case with the trees that grew in the swamps. In the uplands the climate may have been more rigorous (although still summer-like); such a climate always is more favorable to the development of any kind of life, plant or animal.

Through the great coal forests swam and flew and crawled and shambled a boiling malestrom of animal life.

Primitive flying insects droned through the eternal summer of the swamps. One, a primitive dragonfly, had a wing spread of six feet. Never again would the world see such a monstrous insect.

But others grew relatively as large. Some paleontologists, with tongue in cheek, have suggested that the Pennsylvanian should be known as the Age of Cockroaches. The name would

be appropriate, for the swamps literally boiled with these pests. And not, mind you, the little cockroaches which today strike terror to the heart of housewives, but monstrous insects measuring three and four inches long. There were countless billions of them, swarming over the fallen logs and wriggling through the denseness of the vegetation—and there had to be billions of them for the species to survive, for, more than likely, almost every other form of life ate the lowly cockroach.

In addition to the six-foot dragonflies and the four-inch roaches, there were many others—spiders, centipedes, scorpions. Fossil spiders from this period show no signs of spinnerets; the spiders may not as yet have developed the ability to spin webs. Some of the centipedes measured a foot in length and, in general, all the Pennsylvanian insects were larger than the ones we know today. But these giant insects flourished for only the few million years of the Pennsylvanian. In the succeeding period, the Permian, they were cut down to size, and a little after that apparently ceased all development and settled down into the ecological niche which they occupy today, static forms of life that no longer strive for greatness.

Amphibians, descendants of the fish-that-walked, lolled about the swamp. Although fossil remains of them are relatively few, no less than seven orders, 19 families, 46 genera and 88 species have been identified. Such great diversity in the creatures argues that there must have been many of them, despite the finding of few fossils. Most of them were small, perhaps no more than a few inches long. Some larger species ran to a length of 10 feet.

Stupid, slow-moving creatures, the amphibians had broad, flat skulls roofed with heavy bone. There is some evidence that some of them may have had a third eye, a small pineal eye between the normal two. Whether this actually was an eye is unknown. It may simply have been a light-sensing organ.

Evidence of it as a vestigial structure still exists in some of the higher vertebrates.

The eyes pointed upward, so that in effect the creatures looked up rather than forward. The legs were placed at the side of the body, so that the animal was held to a sprawling, waddling gait. They were slow, ponderous creatures, with sluggish habits, and most of them spent more time in the water than they did on land. Some had long, laterally flattened tails which were an aid in swimming. They probably ate insects, fish, and other amphibians. They probably bolted their food without much chewing.

A few reptiles existed during the Late Pennsylvanian, their ancestors certain amphibians that had left the watery confines of the swamp and ventured out on land. But the fossils are few and there is no way to judge how common they might have been. The best guess is that they were not too abundant.

In the seas the brachiopods, the crinoids, and the sea urchins still existed in great profusion. The corals, however, had local rather than worldwide distribution. Our ancient friend the trilobite was all but finished.

For a long while good times had been upon the earth. There had been mountains, but no great general upheavals which operated to change the pattern of the winds or of the ocean currents. It had been summer for a long time—a mild, equable world in which seasons did not occur. There is some belief, in fact, that this may be the normal pattern of earth's climate, that the seasonal climes in which we live today are the exception rather than the rule.

But the long summer was drawing to an end. There were hard times ahead.

12. THE PERMIAN

Day of Judgment

THE PALEOZIC ERA came to a close with momentous changes, not only in America but throughout the world. Before the Permian, the last period of the era, had ended, all the continents stood above the sea, as large as they are now, perhaps in some cases even larger. Great geosynclines which had existed since the beginning of known geologic time, buckled and writhed beneath diastrophic processes. The deep-lain masses of rock which had formed, for untold years, from the sediments which had poured into the ever-sinking basins, rose as massive mountain ranges. While the Appalachians were forming in North America, the Urals were rising out of the geosyncline which had existed for ages in eastern Europe In southern Europe and southern Asia other ranges reared up where once the sea had been.

The larger land masses changed the pattern of the ocean currents, which heretofore had carried the warm water from the equator to the far ends of the earth. An oceanic world tends to be a warm world because free-flowing ocean currents are able to distribute the warmth of equatorial regions toward the poles. But with the full emergence of the continents, the

earth no longer was an oceanic world. The land masses blocked and deflected the ocean currents and restricted them, and new patterns were set up and the earth cooled off.

The massive mountain ranges which rose during the Permian changed the ancient patterns of the winds and weather. Mountains, by blocking low-lying cloud formations, operate to provide plentiful rainfall on that slope toward which the winds are blowing, which leaves no rain for the leeward side. As a result, large deserts developed in the Permian period. The days grew colder and the humidity went down and it was a different kind of world. There was a great dying among the life forms which could not face these changed conditions. Those life forms which could evolve to meet the new conditions evolved into other life forms, or at least into changed life forms, and continued to exist. Those that could not change died out. It was a time of crisis and a time of testing. Those that were fit survived, those that were not simply disappeared. After the Permian the world was not the same.

This did not happen overnight, of course. The change was slow and gradual, with no abruptness. Life that was able to evolve had plenty of time in which it could carry forward the evolutionary processes that would allow it to continue as a species. And there was, more than likely, no abrupt dying out. The species that died out, died slowly.

Evolution often pivots upon strange circumstances.

One of the keys to survival in the dryness and the cold of the late ages of the Permian may have been the ability to lay eggs that were covered by a shell lined with a thin membrane.

Egg laying was nothing new. It had been going on for millions of years. The amphibians all laid eggs, just as frogs do now, but their eggs were covered with no more than a jelly-like membrane. Laid in water, they needed no further protection than the membrane. Oxygen was able to get through

the membrane, and the water in which they were laid kept the eggs from drying up before they hatched.

But with the coming of the drought in the Permian, many water holes and swamps dried up. The eggs of the amphibians, therefore, had a mathematically smaller chance of hatching. In some cases the water holes in which the eggs were laid may have dried up before the eggs could hatch. And there were fewer and fewer water holes in which an amphibian could lay its eggs. The amphibian itself may have been well able to survive the changed conditions, but this meant nothing in the way of survival if the eggs it laid, for one reason or another, failed to hatch.

A situation such as this is the highway to extinction. It would mean that each year there would be fewer and fewer amphibians. And that there would come the day when the amphibians no longer would be the dominant life of earth.

But some of the amphibians earlier had developed into something else—the forerunners of the reptiles. They had divorced themselves from the need to live near water, and the eggs they laid did not need water for protection.

An egg with a hard shell could be laid upon dry ground. Oxygen was supplied by a space between the shell and the inner membrane, which served as a sort of lung. Another membrane held its own supply of water. The yolk held a supply of food for the embryo that grew inside the shell.

A creature laying eggs such as this had a far better chance of its eggs hatching under the conditions which prevailed in the Permian than did the amphibian which must lay its eggs in water.

To start with, the hard-shelled egg probably didn't mean too much as an evolutionary feature. More than likely it was little more than a convenience which fitted in with the creature's ability to survive upon dry land. When the time for laying came, the creature did not need to seek out water.

But with the aridity of the Permian, this ability paid off. The survival value of the hard-shelled egg then became important.

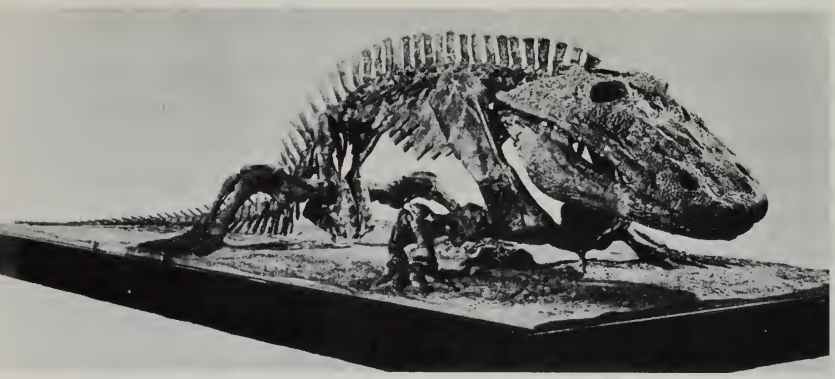
Perhaps the first creature to lay an egg of this sort was *Seymouria,* an ugly, awkward, land-roving animal that looked not too much different from the amphibians from which it had branched. It is so named because its fossil was first found in northern Texas near a town named Seymour.

Seymouria, which may have first appeared in the Pennsylvanian, seems to have become extinct in the Permian. But to take its place were other reptiles which also had developed the ability to lay hard-shelled eggs, and the reptiles went on from there, undeterred by the dryness of the climate, taking over not only in the Permian but in the next era, the Mesozoic.

It may have been in the Permian that something else developed as well as the ability to lay hard-shelled eggs—the ability to make a sound, the first appearance of the voice. For ages the life of earth had been a silent life; it had made no conscious sound. We do not know if the insects of the Mississippian and the Pennsylvanian were noisy, as are many insects today, but in any case an insect sound could hardly be called a voice. It is considered unlikely that the early amphibians had a voice.

But in the Late Permian an amiphibian named *Eryops* apparently did develop the ability to make a sound. Perhaps it was no more than a hair-raising croak, but at least it was a sound of some sort. *Eryops* would have been a terrifying thing to meet. Some eight feet long, it had a huge, ungainly head, and when it opened its mouth it had the gape of a hippopotamus, a gape all out of proportion even to an eight-foot animal. In terms of a mouth, what it had was probably a sort of cross between an alligator's and a frog's. It was built low to the ground and it waddled when it walked and its belly dragged.

At the beginning of the Permian, some 280 million years



Mounted skeleton of *Eryops*.

ago, the mountainous border still stretched from Newfoundland to Mexico along the eastern rim of North America. The region which at one time had marked the Appalachian geosyncline was a broad alluvial plain. Through this plain flowed the sediment-laden streams which emptied in the west into the steadily retreating epicontinental sea.

By the Middle Permian the uplift which characterized the period had become general throughout eastern North America, the beginning of the Appalachian revolution which marked the end of the Paleozoic era. Later in the period the old eastern geosyncline was folded into a lofty mountain range, heaving up some 50,000 feet of rock which had been laid down by the sediments of long ages. The change here was so profound that never again would this region be crossed by any sea.

As the period dawned a shallow sea, creeping around the western end of the mountain chain which encircled the eastern half of the continent, spread north across part of Texas and into Kansas and Nebraska. This sea at times may have covered much of the Great Plains and may, on occasion, have extended as far eastward as Ohio.

As time went on, however, deltas were built out from Llanoria and the Colorado mountains. After many thousands of years these two deltas met, and the outlet of the sea to the

south was closed and the sea was trapped. The climate became progressively more arid. The trapped sea became a vast dead sea occupying the middle of the basin centered over Kansas and Oklahoma. Evaporation exceeded precipitation and the waters grew saline. All of the marine life that lived in the sea died out, unable to exist in the brine. It seems likely that from time to time a connection with the ocean was re-established, somewhere through the present Gulf of Mexico area, which served to fill the dead sea once more with ocean water. But within a short time these channels apparently were closed and the process of excessive evaporation continued, shrinking the area of the sea, making its waters more saline than ever.

Finally the sea entirely disappeared, either because it became filled to sea level with sediments washing off the surrounding land or because the area upwarped. When this happened, streams converging on the now non-existent sea spread hundreds of feet of red mud and sand over not only the basin, but the deserts which had surrounded it.

For a time an extensive area of sand dunes covered a part of Oklahoma. These are preserved today as the Whitehorse sandstones.

In western Texas and southeastern New Mexico another basin, the Guadalupe basin, persisted throughout much of the Permian, holding another dead sea. Before the period closed this sea also had disappeared.

These two dead seas represent the last stand of the Paleozoic epicontinental seas east of the Cordilleran region.

Early in the period a shallow sea invaded the western part of the continent, covering eastern Nevada and part of Utah. A second similar sea flooded northern California. Apparently at this time the nearby land was low, for there are few sediments found in the area covered by this second sea. Rather, there is a thick deposit of limestone, which indicates that the sea may have remained for a great part of the period.

PERMIAN

In the Late Permian, however, volcanoes became active all along the Pacific coastline, extending inland to Nevada and Idaho, signaling the beginning of the extensive igneous activity that would continue in the Pacific borderlands through much of the Mesozoic era. Important centers of volcanism also appeared at this time in southern Alaska and central Mexico.

In the Middle Permian a new geosyncline occupied the central part of British Columbia and reached southward into Washington and Oregon.

As the period drew to a close the Appalachian revolution wrought the most dramatic changes in the land. Tortured convulsions of the earth thrust the ancient land of Appalachia

westward against the old, time-honored Appalachian geosyncline. In the geosyncline 50,000 feet of rocks, laid down through millions of years, folded and buckled, rising into an unbroken chain of mountains all the way from Newfoundland to Alabama. The thrust was so violent that in places the ancient Cambrian rocks were forced up and over the more recent rocks of the Pennsylvanian period and the 500-mile width of the geosyncline was compressed into an area at places no more than 270 miles in width. At the present moment there is no way of telling how high this primitive Appalachian range may have stood, but it is likely that it was fully as high as the Alps are today. Study of the folds found in present-day Pennsylvania indicates that some of the peaks may have risen five miles high. But while the folds might indicate this height, it is unlikely that the peaks ever reached it, for as soon as the mountains started to rise erosive forces began to level them, wearing them away even as they rose. In what is now New England, the folding of the Appalachian revolution was superimposed upon the deformities which marked the uplift of Taconian and Acadian times. As a result, the geological structure of New England and the eastern coast of Canada is extremely complex.

At about the same time, the Ouachita disturbance north of Llanoria pushed the structure of the Ouachita mountains of Arkansas and Oklahoma over the eastern end of the old Arbuckle range.

The only Permian rocks preserved in the eastern part of the United States comprise the Dunkard group, which underlies an area of about 30,000 square miles in southeastern Pennsylvania and adjacent parts of Ohio and West Virginia. This group is made up of siltstones, red shales, and sandstones.

The absence of Permian formations in the east is explained, of course, by the fact that deposition had ceased as the region was uplifted, with the streams that crossed the alluvial plains

carrying their mud farther west, into Kansas and Nebraska, where the great dead sea existed.

The most complete record of Permian times is found in the rocks of Texas and southeast New Mexico. Here the system is nearly three miles deep and divided into four series.

In Europe the Permian rocks of the southern part of the continent are largely marine, while those of the north are continental. In the north, basins which were formed by warping at the end of the Carboniferous period were filled during the Permian by debris washed from the encircling mountains. Apparently there were no great rivers. The debris appears to have been transported for only a short distance, and is imperfectly sorted. The Lower Permian rocks contain many lava flows and intrusions, marking times of igneous activity.

In southern Europe a depression formed early in the Permian to bring in the sea, and at one time during the period a gulf extended across a part of the northern section of the continent.

Asia seems to have been covered by a sea during a good part of the Permian, for the rocks are marine. Much of the coal in China was formed during the period.

Permian glaciation is evident in much of the southern hemisphere. In Australia at least five glacial stages can be recognized. There is some reason to believe that the Australian glaciation may have started early in the Carboniferous and have continued into the Permian. Between the stages there is evidence of extensive volcanic activity. The first glacial deposit runs to only about 100 feet in depth, lying on top of volcanic debris which runs as thick as 2,500 feet. Other glacial periods followed the first. True interglacial intervals exist between each of the five glacial stages. During the interglacial intervals the ice apparently disappeared entirely. Some coal beds were laid down during the intervals, which would indicate a tropical rather than a glacial climate.

In South America glaciation also appears to have been widespread during the Permian, extending from São Paulo in Brazil south to the Falkland Islands, which during Permian days were part of the continental land mass. Three glacial stages can be traced. The first of them could have occurred late in Carboniferous times.

South Africa and India at times during the period also were covered by ice. The ice cap seems to have covered practically all of South Africa, extending north to at least 22 degrees south latitude. Three or four centers of glacial buildup appear to have existed, the most important one being in the Transvaal.

The Permian was one of the great crisis points of the earth's history. For years the massive deposits laid down by the erosive forces of the Paleozoic era had built up points of strain upon the crust. Strained to the breaking point, the crust reacted, cancelling out the strains, striving for a balance which long ages of deposition and erosion had upset. Mountain chains were thrust up where none had been before, unleashing the volcanism which shook the earth and poured out floods of lava. The face of the earth was changed and the climate changed as well. The everlasting summer came slowly to an end and the cold crept in and well-watered areas turned to deserts and for many different kinds of things it was hard to stay alive.

The Pennsylvanian flora lived on into the Permian, but most of the plants were ill-adapted to the oncoming aridity and cold. As the swamps dried up many of them died. Few of them could withstand the colder weather. They would not have died all at once and some of them, perhaps, growing in favored or in sheltered spots, may have persisted for millions of years. But no matter what their persistence, most of them were doomed. By the close of the Permian the great scale trees were almost gone. The cordaites, as such, died out either in the Permian or very shortly after. But in the process of

their dying, they gave rise, through evolution, to true conifers, which have survived into the present. The seed ferns hung on for a time, but died out in the Jurassic period.

The conifers, far better adapted to Permian conditions, flourished and sprang rapidly into the lead as the dominant trees of earth, giving rise to the great conifer forests which cover large portions of the earth today.

The insects, by and large, came through the crisis in fairly decent shape. Gone, of course, were the monstrous dragonflies and the giant cockroaches and the foot-long scorpions, but the insects still remained. They had taken refuge in smallness; most of them that survived the Permian were tiny and some of them minute. Fossils of these insects, because of their delicate structures, have been preserved in only a few places. One of these places is a locality near Elmo, Kansas, where the fossils of thousands of varieties have been found in the rocks of the Lower Permian. Other finds have been made in Oklahoma, in the Dunkard series in Ohio, and in the Lower Permian of Russia. All the fossils show changes from the Pennsylvanian insects. Spurred by the change in the climate and in living conditions, the insects were evolving. Many new orders were arising, forerunners of the insects of today. Mayflies, unknown in the Pennsylvanian period, were common in the Permian. True dragonflies made their first appearance and the first beetles appeared.

Among the vertebrates, amphibians still were present in fair number. Many of them, driven from their swampland homes, found new homes in streams. But the amphibians were doomed. Over the ages they would largely disappear, unable to hold their own in this different world.

As the amphibians faded away, the reptiles increased greatly in numbers and variety. Before the close of the Permian they were dominant not only on the land, but had adapted themselves to aquatic life, in both fresh water and salt. Before the period ended they had established themselves as masters of

the earth, a mastery they would not relinquish for almost a hundred million years.

The great range of specialization in the Permian reptiles attests to the rapidity of their evolution. Most of them had long bodies and long tails. Most of them had short legs. Some of them were agile and lizard-like; others were sluggish and semi-aquatic. Some others were thick-bodied with only stubby tails. Many of them had sharp teeth, built for holding and for shredding, and plainly were flesh-eaters. Others had blunt teeth admirably adapted for the crushing of shells. Still others were toothless and may have been plant-eaters. They can be divided into several distinct orders, but none of these orders correspond to any presently living groups. They ran to no great size; the largest of them probably was no longer than 15 feet. The most bizarre of the lot were the finbacks, so called because of the greatly extended neural fins along their backs. These creatures had the appearance of carrying sails. There must have

A group of finbacks bask in the sun.

been a reason for this kind of appendage, for nothing in nature seems to be entirely purposeless. But if so, no one as yet has been able to figure out what that purpose might have been.

Most significant to us are a group of stout-bodied, flesh-eating reptiles known as theriodonts. They are significant because they foreshadowed the advent of the mammals. Unlike other reptiles, they had teeth differentiated into incisors, canines, and molars. What is more, they carried their bodies off the ground instead of sprawling. Other details of skull and jaw structure confirm their ancestral relationship to mammals.

They were not mammals. They still were reptiles. But in their teeth, their stance, their skull structure, they showed those features which later were found in primitive mammals. They are known chiefly from Upper Permian and Triassic fossils found in South Africa and from other fossils in equivalent rock formations in the Permian basin of Russia.

In the ocean the cephalopods continued to evolve, giving rise to the ammonites, a group of now extinct mollusks related to the chambered nautilus of today. The ammonites, in coming ages, were destined to rise to dominance among the invertebrates. Yet, strangely enough, they came perilously close to extinction in the Permian. Of 13 families which flourished in that period, only two survived into the Triassic period. Of these two, one died out early and only one was left. But this one, lone family, in a spurt of evolution, accounted for the many tribes of these animals that populated the seas of the Mesozoic era.

By the end of the Permian the last of the trilobites were gone. So were many of the crinoids, which had lived in profuse numbers for millions of years in the warm and shallow seas of a more kindly climate.

During the Permian natural selection operated, as it always does, in utter ruthlessness. And as a result the old free and easy life was swept away and a new life trod the earth.

13. THE TRIASSIC

Dawn of the Reptile World

THE PALEOZOIC ERA had been a time of quiet. For a great part of it the land had lain bare. When life crept upon the land, it was not a fearsome or ferocious life. It was a life grotesque in many ways, but unspectacular and usually rather small.

But now came a new era, the Mesozoic, thunderous and ferocious. Giant killers stalked the earth. Huge marine reptiles splashed and slithered through the seas. Winged dragons rode the air. And during a part of this era certain little life forms skittered timidly about, crouching and hiding against the violence and the hunger in the land. These were the forerunners of the mammals that in another era would succeed the reptiles in the dominance of earth.

The Mesozoic era began about 230 million years ago and comprises three periods: the Triassic, which ended about 181 million years ago; the Jurassic, which ended 135 million years ago, and the Cretaceous, which some 60 million years ago gave way to the Cenozoic era, the age of the mammals in which we live today.

The Mesozoic era often is called the Age of Reptiles. To explain the reptiles, we must go back a bit.

In the last days of the Pennsylvanian period, the amphibian that had forsaken the water and had evolved into a creature which laid a hard-shelled egg probably was more reptile than amphibian, a form of life existing in that shadowy borderland where one form of life is slowly evolving into another form of life.

The first true reptile is known as cotylosaur, which means "cup-lizard." The name is derived from the cup-shaped ring of the vertebrae. With the development of the cotylosaurs in the Permian period, the amphibians definitely have been left behind and the evolutionary break is clean. Here we are dealing with a reptile, a new kind of creature that for millions of years would overshadow every other form of life on earth. The cotylosaurs are the foundation stock of all that vast assemblage of reptiles which make the Mesozoic an era of dramatic impact.

Today we have surviving only three main groups of reptiles: the tortoises and turtles, the snakes and lizards, and the crocodiles. During the courses of their evolutionary development, the reptiles gave rise to the mammals and the birds, but the reptiles themselves, except for a few insignificant survivors such as snakes and turtles, died of unknown causes at the end of the Cretaceous period.

When one mentions the Mesozoic era and the Age of Reptiles, most people automatically think of dinosaurs. And while the dinosaurs were a numerous and spectacular tribe and a dominant and overpowering life form, we should always remember that they were only one branch of the reptile family—the dinosaurs are not the entire story of Mesozoic life.

The evolution of the reptiles, starting in the closing days of the Pennsylvanian period, was comparatively rapid and diverse. There seem to have been few forms of physical specialization that the reptiles did not try, and as a result we now know of thousands of different kinds of reptiles. In South Africa, in formations which were laid down in either the Late Permian

or the Early Triassic (or which may have overlapped the two periods), more than a thousand different kinds of fossil reptiles have been discovered. In this vast reptilian cemetery in the Karoo formation there may be many others. Most of these fossils, of course, are those of the cotylosaurs, the basic family of reptiles from which, apparently, all other reptiles sprang.

The cotylosaurs, in general, still retained many of the characteristics of the amphibians, from which they had evolved. The legs still were placed to the side of the body instead of underneath it, so that the animals still waddled when they walked. But the body, even so, was lifted somewhat off the ground and some progress in the science of locomotion could be noted. The bodies still tended to be heavy, but some of the reptiles were becoming streamlined and that was another point of progress.

Many of the cotylosaurs died out in the Permian. Still chained to the inefficiency of their amphibian ancestors, they were unable to survive.

But others of them evolved and continued to evolve, giving rise to the much more efficient life forms of the Mesozoic. Still others, evolving in other directions, were the forerunners of the mammals and the birds, which still exist today.

Many groups of reptiles descended from the cotylosaurs, but of them three are the most interesting. The therapsids were in the direct line of descent of the mammals, the connecting link between the most primitive forerunners of the reptiles and the many mammals which are alive today. The pelycosaurs gave rise to some of the more spectacular of the early reptiles and were closely associated with the line which gave rise to the mammals—not our ancestors but our cousins far-removed. The third group, the thecodonts, were the ancestors of the dinosaurs and of a great variety of other Mesozoic life forms, including the phytosaurs (primitive crocodiles) and the flying dragons, the pterodactyls.

Mammal-like Triassic reptiles confront a "giant head."

Dinosaurs are divided into two orders, based upon the structure of the pelvic bones. While all dinosaurs arose from one common ancestor, they diverged along the way. The pelvic structure (hip bones) of the order *Saurischia* is reptilian in conformation, with the pelvic bones resembling those of a crocodile. In the order *Ornithischia* the pelvic structure resembles that of a bird.

Most of the Triassic dinosaurs were reptile-hipped. A few of the bird-hipped dinosaurs show up in the fossils of the Upper Triassic.

In general most of the *Saurischia* were flesh-eaters and walked on their hind legs, although one branch of the group

took up plant-eating. All of the *Ornithischia* were plant-eating creatures, and the greater number of them traveled on four legs.

After the Appalachian revolution of the Permian period, the Appalachian mountains, in the eastern part of the United States, remained fully emergent for two geological periods. There was far more land above the water then, so far as North America is concerned, than there is today: the continental shelf which today extends some 200 miles into the Atlantic ocean, then lay above sea level.

About the middle of the period, the Appalachian mountain chain was subjected to a faulting process which, through long ages of lifting some parts of the earth's surface and depressing others, resulted in downfaulted troughs. The extent of the upward faulted portions of the mountain chain is unknown, nor does there seem to be any way to know how much higher the mountains may have been thrust. The troughs, however, contain thick layers of sediment which measure upward of 20,000 feet. We know that the faulting extended from Nova Scotia as far south as North Carolina, but deep wells drilled in Florida have penetrated redbeds so similar to the sediments in the other troughs that it is considered likely the faulting extended along the entire Appalachian range. The strata found in the troughs have been named the Newark group from prominent exposure found near Newark, New Jersey. There is evidence here and there that at times lava may have welled out of fissures in the earth and flowed into the basins.

No marine fossils are found in the Newark beds, but freshwater fish and land plants are abundantly represented. And nowhere in the world have more dinosaur tracks been found.

Streams from the uplifted mountains, during the rainy season, carried tons of muds suspended in the rushing torrents that spread across the basins. Once the rains were finished, the muds lay steaming in the sun. Dinosaurs traveling across

these muddy flats left their tracks behind them. During the dry season the mud became hard and sun-baked. Wrinkling and cracking destroyed many of the tracks, but some would remain. The next rainy spell would bring another flood of mud, and the tracks that were left would be covered. As time went on, the mud turned into rocks and the tracks of these traipsing dinosaurs were preserved in solid stone.

Also found in the bedding planes of these rocks are fossil ripple marks of evaporating puddles, mudcracks, and fossil raindrops, recording the final spatter of a passing shower.

While the Newark group are the only Triassic rocks found in the east, many formations in the west date back to the period. By far the greater number of these rocks are of continental origin, formed from the debris washed off the western highlands into troughs and basins. Occasionally, however, there

Fossil tree trunks from petrified forests at Yellowstone National Park in Wyoming.

are narrow belts of marine rocks, marking places where fingers of the far western seas crept east.

The most spectacular of the west's Triassic formations can be seen in Arizona's Painted Desert. Here gigantic redbeds of continental origin range in color from bright red to deep maroon.

North of the Colorado highlands most of the redbeds date to the Lower Triassic, those south and west to the Upper Triassic. There is no clear evidence of Middle Triassic rock.

In Utah and Arizona, Triassic formations range to a thickness of 4,000 feet and are divided into four widespread units, the Moenkopi, Chinle, Wingate and Moenave formations—the first-named the oldest. The Moenkopi, a Lower Triassic formation, was deposited by streams, although in occasional areas there is some evidence of marine intrusion. The Chinle is the formation that gives the Painted Desert its glowing color. It contains considerable ash from volcanoes in California and Nevada. Tracks of reptiles and large amphibians have been found and fossil wood is abundant, particularly in the petrified forest area of eastern Arizona.

Some of the petrified logs are up to ten feet in diameter and 120 feet long. They are mostly conifers, and apparently do not lie in their original position. Geologists believe they grew along rivers, on higher ground, and were washed away by floods. Some of them still have the stumps attached; they may have grown close to the river bank, tumbling into the water and being swept away when the rushing water of floodtime undermined them.

The size of the logs and the thickness of their growth layers indicate that the growing season was long, that there was plenty of moisture, and that the annual cold or dry season was of short duration. A few of the petrified trunks have fluted bases, such as are found today in cypress trees. These may have grown in upstream swamps.

EARLY TRIASSIC

In the far west an early Triassic sea covered a good part of southern California, finally spreading northeast into parts of Nevada and Utah and northward into the Canadian province of Alberta. This sea laid down thick beds of gray shale and limestone, rich in marine fossils. At the same time non-marine redbeds were accumulating over the lowlands to the east, in Montana and Wyoming and parts of South Dakota, Nebraska, Kansas, and Colorado.

Realignment of the major geological structure of the western part of North America began in the Middle Triassic, effecting changes that would dominate the rest of the Mesozoic era. An area of uplift began forming in eastern Nevada, gradually

extending north across Montana and Idaho and deep into Canada. This was the beginning of the Mesocordilleran geanticline, which was to culminate in a mountainous highland in Late Jurassic and Cretaceous times.

At the same time a new trough, the Pacific Coast geosyncline, was forming along the western edge of the continent, extending from Alaska to southern California.

Simultaneously a third major geological feature made its appearance—a trough that began to sink along the eastern edge of the Mesocordilleran geanticline in Canada, This was the forerunner of the great Rocky Mountain geosyncline.

Late in the period, volcanic action on a large scale took place in many areas from northern California through British Columbia and into Alaska.

In Europe the southern part of the continent was covered by that vast epicontinental sea which had lain in the Mediterranean geosyncline for millions of years, extending east into Asia through the present Himalayan area, then bending south into the Pacific. Marine deposits laid down in this sea can be seen today in the peaks of the Tyrolean Alps.

Triassic formations in the rest of Europe are chiefly redbeds of continental origin. In France some of these beds are salt-bearing and in Germany some beds of gypsum have been found.

Triassic formations in South Africa also are non-marine. The earlier formations, some of which are very thick, are overlaid by volcanic material and are shot through with massive intrusions. At some time late in the Triassic the area underwent a time of extensive volcanic activity. The lower part of the Triassic series is composed of sandstone, siltstone, and shales, which include thin beds of coal and abundant plant fossils. Above these formations are thick redbeds, showing the typical fossil mudcracks and containing the fossils of reptiles. Overlying the redbeds are sandstones formed from wind-blown sand, in some places to the thickness of 800 feet. Geologists interpret

this as a sign of growing aridity and extensive desert conditions toward the end of the period.

Triassic formations in Brazil present much the same picture. Late Triassic redbeds are overlain by enormous lava flows which cover some 30,000 square miles to a depth of from 400 to 2,000 feet. It is possible, however, that the volcanic outburst may not have occurred until the Early Jurassic.

India stood above the sea during the entire period, perhaps as an island. There is some reason to believe, despite lack of positive evidence, that during part of the period it may have been connected to Africa by a land bridge.

Many of the Pacific islands have marine Triassic rocks, but in Australia the deposits are continental. So we know that this continent also stood above the water. Coal beds in New South Wales date from the period.

New Zealand apparently had some glaciation, and the same is true of Africa. Tillite, containing glacial boulders, has been found west of Lake Tanganyika, only five degrees south of the equator.

The harsh climate of the Permian seems to have overlapped into the Triassic, although there is no evidence of wide glaciation. During much of the Paleozoic era the climate had been about the same all over the world, a perpetual summertime. But in the Permian and Triassic the climate varied from one locality to another, as it does today. Toward the end of the Triassic the climate grew milder and the world headed once again into a long season of eternal summer.

The plant life of the Triassic still is very imperfectly known. Fossils of fewer than 40 species have been found, and the greater part of these are from the Upper Triassic. This lack of plant fossils is due, in part, to unfavorable conditions for the preservation of fossils, but there may be another factor as well—the actual impoverishment of plant life because of harsh climatic conditions. In the Pennsylvanian period we have

a rich record of the plant life, not only because of conditions favorable to the preservation of fossils, but on account of the sheer bulk of vegetation as well. In the Triassic, vegetation in many areas may have been scanty.

The chief groups of Paleozoic plants were extinct or nearly so by Triassic times, killed off by the rigors of the Permian period. Here and there some of them may have hung on under marginally favorable conditions, but if so they were waging a losing battle. Ferns and scouring rushes, we know, still remained, but in reduced numbers and much reduced in size from the exuberant growth of Mississippian and Pennsylvanian days.

In the thick shales of the Newark group of rocks in the eastern United States, principally in Virginia and the Carolinas, some swamp plants—rushes and ferns—are preserved as fossils, but by far the richest fossil fields lie in the numerous petrified forests found in the west. While these fossils are mostly of trees which have been turned into agate, some smaller plant fossils also can be found.

The agatized logs are very similar to our conifers of today and mixed with them are cycads, a family of primitive, seed-bearing trees, palm-like in appearance. The underbrush which grew in the Triassic forests was composed of ferns, tree ferns and scouring rushes.

The dinosaurs made their first appearance in the Triassic, and before its close had established complete domination of the land. The dinosaurs carried their bodies well off the ground and their legs were placed under the body rather than to the side. This made it possible for them to run, while most of the other reptiles could achieve little better than a rapid, sprawling waddle.

Compared with the monsters of later periods, the Triassic dinosaurs were not particularly terrifying beasts. Nearly all of them were of rather slender build, and few reached a height

Leaves of a cycad from Petrified Forest, Arizona.

of more than 15 feet. Almost all known dinosaurs of the period were bipedal, running on two legs. Their hind legs and tails were powerfully muscled. The tail was lifted off the ground as the creature ran, and helped give balance to the body. Fossil tracks prove that they ran rather than hopped, as is the case with the kangaroo, which also is equipped with strong hind legs and a heavily muscled tail.

Many fossil tracks of dinosaurs are found in Triassic rock, especially in the eastern section of the United States, but fossils of the animals themselves are rare.

The mammal-like reptiles of the order *Theriodonta* made their first appearance in the Permian, continued through the Triassic, but died out in the following period, the Jurassic. By this time, however, they had given rise to true mammals. Fragmentary remains of small mammals have been found in southern Wales and across the Bristol channel in England. It

is still uncertain, however, whether the fossils of these tiny animals belong to the Late Triassic or the Early Jurassic. The remains are chiefly jaw fragments and teeth, but the structure of the teeth makes it clear that three distinct orders of mammals existed at this time. All of them probably lived in crannies and crevices in the rocky uplands, which afforded them an opportunity to evade reptilian predators.

Many phytosaurs lived in Triassic streams. These creatures superficially resembled modern crocodiles, but were not closely related to them. One set of bones found in west Texas proves that some of the creatures measured 25 feet in length.

Marine reptiles made their appearance in the Early Triassic, but apparently did not become common until late in the period.

The ichthyosaur, a great sea monster which resembled the modern dolphin in appearance, first shows up in the Late Triassic seas. It developed rapidly into one of the dominant groups of marine life of the Mesozoic era. The ichthyosaurs measured up to 60 feet in length. Fossils of this length have been unearthed in California and in Oregon. The structure of their flipper-like limbs indicates that they originated with a land-dwelling animal which had returned to the sea—a case of reverse evolution—the legs modifying into flippers. They had fish-like bodies with powerful, laterally-compressed tails. With this tail and their mighty flippers, they undoubtedly were fast swimmers. Wolves of the sea, they must have been the terror of fish and other marine life.

The Triassic seas swarmed with a vast number of ammonites, many of them far larger than those of Permian days. Near the end of the Triassic they came close to extinction, but one genus survived into the Jurassic and in that period gave rise to many diverse forms. The end of the ammonites came in the Cretaceous period, at the end of the Mesozoic era, when they joined in the great dying that all but wiped out the reptilian world.

14. THE JURASSIC

The Day of the Dinosaur

SUMMER CAME BACK to the world in the Jurassic period. Temperatures seem to have declined slightly at the end of the Triassic, but in the Jurassic the epicontinental seas again spread over much of the earth's surface and the climate moderated. From the middle of the Jurassic the period was marked by a very mild climate, even in the higher latitudes. Most of the United States and Europe probably was subtropical. Coral reefs extended 2,000 miles north of their present range. Coral is one of the most reliable temperature indicators. It will survive only in water that is warm the year around. Great dinosaurs roamed as far north as Montana and Mongolia, and paleontologists are fairly well agreed that dinosaurs could not have withstood freezing weather.

Early in the Jurassic the insects were small; it is believed that this dwarfing was the result of colder weather in the Late Triassic. But by the time the Jurassic period closed the insects had grown larger. And along with the warmer temperatures, there seems to have been more rainfall. While local arid conditions existed, sometimes in large areas, the Jurassic was a period during which most of the land was well watered.

The Jurassic can best be studied in Europe, for at the start of the period shallow seas spread widely over the continent. Formation after formation of limestone and shale was laid down. To this day, in many parts of Europe, the Jurassic rocks still retain an undistorted record of that time—the rock strata lie, one upon the other, book-fashion.

In contrast, the record of the rocks in North America is less widespread for the Jurassic than for any other geological period. Whatever record there is lies in the west. The Appalachian region still stood high during the period and extended far beyond the eastern edge of the present continent. As a result, all deposits eroded to the east now lie somewhere at the bottom of the Atlantic Ocean. And, for some reason, basins for the depositing of sediments carried by westward-flowing streams have not been found. The only traces of Jurassic rock known in eastern North America are some deeply buried formations along the Gulf of Mexico, where deep well drilling has discovered them.

Early in the Jurassic a sea moved south from Canada, creeping along the trough which first appeared in the Middle Triassic east of the newly established Mesocordilleran geanticline. By the Middle Jurassic this sea had extended itself as far south as New Mexico and Arizona and had spread eastward into North and South Dakota. Because it occupied the site of the widespread Sundance rock formations of the northern Great Plains, it is known as the Sundance sea. Late in the period the Sundance sea withdrew and the streams flowing eastward, off the still-rising Mesocordilleran highlands, spread a sheet of mud, gravel, and sand over a vast area of the interior lowlands. This great sheet of sediment today forms the rocks of the Morrison formation, famous for the richness of its fossils, carrying an amazing record of the land life of the time. This is the favorite hunting ground for the dinosaur, whose fossilized remains are widely scattered throughout the rock.

All the fossils of the gigantic dinosaurs of the American Jurassic have come from this single formation, which is named for Morrison, Colorado, near Denver, where there are prominent exposures of the strata. The formation extends to the north into Montana, west to Utah, and south into New Mexico. It consists of shales, siltstones, and sandstone with considerable local conglomerate. The color of it varies locally—grayish-green, lavender, black, pink or white. It covers in the neighborhood of 100,000 square miles of the Rocky Mountain region, but at no place is it more than 400 feet thick.

No marine fossils have ever been found in the Morrison formation; apparently it is entirely continental in character. Fossils of more than 150 kinds of animals have been found in the beds, including dinosaurs, tiny primitive mammals, land snails and plants. It is difficult to place the formation squarely in the Jurassic period; there has been, at times, some belief that it may date from the Early Cretaceous. But comparison of the dinosaur fossils found in the Morrison with other dinosaurs of the Jurassic and Cretaceous in Europe makes it seem clear that the Morrison does date to the Late Jurrasic.

The Sundance formation, which underlies the Morrison, consists of two major units—the Gypsum Springs rocks of the Middle Jurassic, and the more restricted Sundance rocks from the early portion of the Late Jurassic. Both units are made up of shale and sandstone, with thin limy zones bearing fossils of marine life.

Apparently the Sundance sea was extremely shallow, its level fluctuating. At no place do the two formations laid down beneath this sea measure as much as 300 feet. Near the western border of Wyoming, however, the formation thickens and grades into the Twin Creek limestone of Idaho and north-central Utah. This limestone is 5,000 to 6,000 feet thick, and marks the site of a more persistent sea which lay in the rapidly sinking geosyncline east of the Mesocordilleran highland.

In the west, beyond the highlands, the land was even more widely submeged than it had been during the Triassic. Limestone formations of great thickness accumulated there during the Jurassic, and there is evidence of heavy volcanic activity during a good part of the period.

By the beginning of the Middle Jurassic the sea began to encroach on the coastal belt bordering the Gulf of Mexico. At its greatest extent, this invading sea covered some of Alabama and Mississippi, the greater part of Louisiana, and most of eastern Texas. The deposits laid down by the sea now are deeply buried and are revealed only by well drilling. Within

MIDDLE JURASSIC

the formations lie large bodies of salt. These probably mark the locations of lagoons trapped on the coastal plain and indicate arid conditions extending over a long period of time.

Toward the end of the period the western part of North America experienced its first significant orogeny since the Precambrian. This disturbance, known as the Nevadian disturbance, was the forerunner of a mountain-building period which continued into the Cretaceous period, culminating in the formation of the Rocky Mountains. Pressures coming from the west squeezed the Paleozoic and Mesozoic sediments which had been accumulating for millions of years in the Pacific Coast basin into long folds. The pressure was so intense at times that some of the rock strata were turned on edge. The disturbance extended from western British Columbia into California, affecting the Cascade area of Washington and Oregon, western Nevada, and the Sierra Nevada region.

The sedimentary rock was invaded from below by huge masses of molten rock which welled up, distorting the crust and hardening into batholiths of gigantic size. Erosion has stripped much of the sedimentary rock off some of the batholiths, and these great domes now stand out in all their rugged splendor in Idaho, at Yosemite Park, and elsewhere in the west.

In the midst of all this disturbance solutions carrying gold and silver found their way into cracks and fissures as the tortured land arose, forming rich mineral veins along an extensive belt. Among the deposits formed at this time is the famous Mother Lode, a narrow band of gold-bearing veins running in a straight line for nearly 130 miles between Mariposa and Eldorado counties in California.

The Jurassic seas flooded a large part of Europe and Asia, extending over areas which had been dry land for millions of years.

In the early part of the period the Tethys sea, which for

ages had occupied the Mediterranean basin, sent out a long arm which spread into England, but did not at that time advance over eastern Europe or into Asia. There is some indication that at this particular time both eastern Europe and Asia may have been slowly rising. But if this were the case, it was only a temporary situation, for in the Middle Jurassic the sea spread more widely over Europe and in the last third of the period large parts of both Europe and Asia were covered by water. Much of this inundation came as an extension of the Mediterranean waters, but in central and northern Russia the invading sea was an extension of the Arctic Ocean. Through all of this, India remained above the waters as an island.

As a result of the watery invasion, Europe is rich in Jurassic rocks and perhaps the most interesting of them is the lithographic limestone, a remarkably fine-grained limestone found in various localities in southern Germany. The stone occurs in isolated, lens-shaped masses in the dolomite laid down by the ancient seas. It does not in any case exceed 75 feet in thickness.

The lithographic stone was formed from extremely fine-grained ooze and probably was deposited in shallow water under quiet conditions, since the fossils found in the rock are in perfect condition and not torn apart or scattered, as so often is the case. The lenticular masses of the stone are believed to represent the locations of lagoons along the shoreline of a Jurassic sea.

The stone is a storehouse of the most beautiful fossils ever found—not fossils in the sense of petrified bones, but impressions and carbonized films which, in many cases, show the entire creature, including the soft parts. Here is much the same situation as existed in regard to the Cambrian fossils found in the shale on Mount Wapta in British Columbia. As well as fine impressions of ancient life forms, numerous fossil tracks and trails exist, made by animals at low tide when the mud flats were exposed.

Fossils of some 450 life forms have been found in the quarries near Solenhofen, Germany. These include, beside the famous imprints of the flying birds, *Archaeopteryx* and *Archaeornis,* great numbers of crinoids, ammonites, insects, horseshoe crabs, turtles, crocodiles and marine reptiles. Twenty-nine species of flying reptiles have been identified there, and a lone dinosaur which may have waded out too far in the lagoon and been mired.

Like North America, most of South America stood as dry land during the Jurassic period. Rocks formed by marine deposits are fairly well confined to the Pacific rim of the continent and the Andean region. The Andes, of course, did not as yet exist. Some marine sediments are found in Argentina, marking the thrusting out of a gulf from the Pacific. The rocks of the period give evidence of a good deal of volcanic activity.

Eastern Africa was covered by a bay of the Indian Ocean. Most of Madagascar (Malagasy Republic) was under water, although the southern tip of it may have been tied in with the land bridge which seems still to have connected South Africa with India.

The Jurassic landscape would have had a familiar look to us. The forests were of pine and other conifers. But there was no grass as yet, and what today would be grasslands was clothed with a growth of ferns and cycads, which bore large and showy flowers. The forest underbrush most likely was largely ferns and scouring rushes.

But while there were no grasses, there is some evidence that angiosperms were present. Spores of water lilies and magnolia have been reported from Scotland, and if this is the case, then one of the significant developments in the plant world can be traced back to the period.

Angiosperms are flowering plants in which the seed is enclosed in a protecting case or in a fruit. They are the highest development of the plant kingdom.

Jurassic shoreline scene.

Grasses, nut and fruit trees, cereals, and most of the vegetables cultivated by man are included in the angiosperms. It is upon the angiosperms that man's agriculture is based.

But the basis of agriculture is not the only consideration here. The angiosperms also provided food for the mammals which still were waiting offstage for their cue. So long as the dinosaurs held sway and cereals and fruits had not become common, the mammals could only wait their turn.

The forests were beginning to have a familiar look; much the same can be said of the world of insects. About 1,000 species of insects have been identified from the Jurassic, among them are representatives of most of the modern orders. The true flies (*Diptera*) made their first appearance in the period and so did the ants. The cockroaches, old hands by now, were still around, but the grasshopper and the moth were newcomers. Other common insects present in the Jurassic were caddis flies, scorpion flies, dragonflies and beetles.

The Age of Reptiles now was in full swing, not only on the land, but in the sea and air.

When a person thinks of a dinosaur, he is apt to think of the four-legged, huge-bodied, long-necked, long-tailed creature that has become the familiar trademark of Sinclair Oil. There were plenty of such creatures about in the Jurassic; they are known as sauropods. Plant-eating animals, they spent most of their time in water. They probably were unable to swim, but the buoyancy of their huge bodies would have made getting around in water a fairly easy matter. At times they walked along the bottom of the shallow lagoon or lake in which they fed. At other times, in slightly deeper water, they may have floated. Reaching down to touch bottom with a foot, a slight push would propel them in any direction they desired. But they may not have had to move around too much. With such a long neck, they could cover a large feeding area before they had to move.

They were huge animals—the smallest of them no less than 30 feet in length. The largest (or at least the longest) of them was *Diplodocus,* which reached a length of 85 feet. Another, *Brachiosaurus,* while not as long as *Diplocodus,* may have weighed close to 50 tons, the heaviest land animal known to have existed. *Brontosaurus,* the character that springs to the public mind as representative of dinosaurs, measured out at no more than 65 feet, but, weighing in at 30 tons, probably was heavier than *Diplodocus,* who was skinnier and more streamlined than most of the sauropods.

Such weight and bulk would have been almost impossible to handle if the creature had been forced to live on land. But with the buoyancy of the body in the water, the disadvantages of such weight were cancelled out. Living in water, the sauropods were beyond the reach of most predators; they would have been subject to attack only on those rare occasions when they ventured out on land. Even then, the sheer size of them must have warned off all but the hungriest and most foolhardy of meat-eaters.

Their one concern throughout life must have been the ingesting of sufficient food to sustain their tons of flesh. There is no doubt that they necessarily were vegetarians, depending for fodder upon the rich growth along the edges and at the bottom of the lagoons. But they may have been indiscriminate. They could not have afforded to be fussy eaters. Anything that came along may have been food for them. There is a possibility that they were not above the eating of carrion if they chanced upon it, and anything alive that moved within the reach of that long neck might have been acceptable and quickly gobbled up.

Of the carnivorous dinosaurs during the Jurassic, *Allosaurus* is the most typical. Measuring 34 feet from snout to tail, the great predator may have weighed up to 14 tons. Walking on his hind legs, his forelegs were reduced in size to a point at

which they must have been entirely useless. His jaws were monstrous, equipped with three-inch teeth. His legs ended in three toes, each armed with a wicked recurved claw. And once again, his problem must have been that of getting food enough to sustain his 14 tons of flesh. *Allosaurus* must have been continually on the prowl, hunting down his victims, overwhelming them in a short and brutal rush, holding down their bodies with a clawed foot while with his jaws he tore off great chunks of flesh, probably gulping it since his teeth were ill-equipped for chewing.

Another Jurassic dinosaur was *Stegosaurus,* a plant-eating, four-legged, land-going creature 30 feet long and weighing 10 tons. Equipped with a head ridiculously small for the vast bulk of his body, he sported two rows of bony plates mounted loosely along his back, and spikes at the end of his stubby tail.

Why *Stegosaurus* carried the two rows of armor plate along his spine is still a puzzle to paleontologists. They may have given some protection to that single area of his body, but why that one area should have been protected when the great paunchy body was wide open to attack is a bit hard to explain. It may be that the plates were intended to make *Stegosaurus,* essentially a mild and inoffensive beast, appear more ferocious than he was, but this thought is no more than supposition.

In addition to these three types of dinosaurs, there were many others, a good number of them small. The plant-eaters outnumbered the carnivores by a wide margin, a rule of nature that still exists today, for if they did not, the plant-eaters would be quickly wiped out by the predators, which then would become extinct due to the disappearance of their source of food.

We have seen how in *Allosaurus* the front legs dwindled until they were useless, or nearly useless, appendages. In the flying reptiles, which first appear in the Jurassic, exactly the

Pterosaurs soar and glide.

opposite is true. Progressing along a divergent line of evolution, the winged reptiles developed the front legs into a specialized structure while the hind legs became almost entirely useless.

Most of the Jurassic flying reptiles were small, many of them no larger than sparrows or robins. A few of them were about the size of small hawks. One monster, *Rhamphorhynchus,* had a wing span of 30 inches. Later, in the Cretaceous period, the flying reptiles grew larger. One of them, *Pteranodon,* had a wing spread of more than 20 feet.

To call them flying reptiles is somewhat misleading. They didn't really fly; what they did was glide. The wings were far less complicated in structure than the wings of a bird. In the development of the reptile wing, one finger of each forearm had grown into a long boom to which was attached a bat-like membrane which was in turn attached to the thigh. The wings could not be flapped. Rather, they formed a plane surface which allowed the reptile to soar and glide, taking advantage of the wind currents.

The flying reptiles are known as pterosaurs or pterodactyls, which are interchangeable terms. How they came to follow the evolutionary trend which led to the development of wings is not known, of course. There is speculation that, to start with, they may have been tree-dwellers and that the membranes extending from forearm to thigh may have been developed as an aid in jumping from one branch to another or from one tree to another—exactly as do our flying squirrels today.

As the survival value of the wings became apparent, further evolutionary developments would have followed to take full advantage of the ability to travel in the air. The animal was reduced in weight, always a consideration in flying, by the bone becoming hollow, as is the case with birds. The breastbone was enlarged and strengthened to serve as an anchor post for muscles used in flight. The tail in time developed a fin to give the flying creature more stability.

It is likely that the pterosaurs spent virtually their entire lives in the air. As the development of their flying ability continued, their hind legs became useless. On land, the pterosaur probably was forced to awkwardly support itself on its wings and could move only by fluttering about. Once landed, it might have been a considerable problem for it to launch itself into the air again.

Most fossils of pterosaurs have been found in rocks which mark the sites of ancient river estuaries or shallow sea bottoms. The creatures apparently found such places good hunting grounds for insects and fish, which probably formed a great part of their diet. Some of those whose fossils are found may have miscalculated in a dive to scoop up a fish, and have fallen into the water and drowned.

One puzzle which has not been solved, and which may never be, is whether the pterosaurs might have been warm-blooded rather than cold-blooded, as was the case with the other reptiles. Flight is a strenuous business, and calls for a highly efficient use of energy intake. Birds, for example, have a significantly higher metabolic rate than do mammals. This has led to the speculation that the pterosaurs were, to some extent, warm-blooded and may have had a circulatory system considerably improved over that of the other reptiles.

The same evolutionary trend which brought about the development of the pterosaurs also culminated, in the Jurassic, in a more significant and eventually more accomplished flying creature—the first bird. The first fossils of ancient birds came to light in Europe's lithographic stone, which also holds the first fossils of the flying reptiles.

Fossils of two birds—*Archaeopteryx* and *Archaeornis*—were found in the stone. Both birds were about the size of crows, and at first they were believed to be of the same genus. However, closer examination showed some differences in structure.

Both of the fossils bore many reptilian characteristics. The

Fossil *Archaeopteryx* (left) and reconstruction (right).

tail was long, composed of 20 vertebrae, the jaws held teeth and the skull was of true reptilian shape and structure. But the fine detail in the stone showed an imprint of feathers (a development from reptilian scales), and the presence of feathers marked the fossils as unmistakably those of birds.

These ancient birds probably were rather clumsy fliers, and may have spent as much time running on the ground and clambering through the trees, in their search of insects and reptiles small enough to gobble, as they spent in flying.

In the Jurassic oceans the ichthyosaurs, which had first appeared in Triassic times, were joined by the *plesiosaur,* a terrible creature with a barrel-like body and an extraordinarily long neck. The largest of these sea dragons measured between 30 and 40 feet in length.

The ichthyosaur swam by the undulating movement of its

body; the plesiosaur rowed itself along the surface of the water by the use of four paddle-like flippers. It probably could not develop impressive speed, but its long neck (23 feet long in the case of one species dating from the Cretaceous period) would have given it wide hunting range.

The Jurassic was a ferocious time of hunting down and killing, of beasts driven by a mindless hunger. The land and the sea and air were filled with strange creatures that perhaps more than anything else would remind us, if we could see them, of the terrible ogres and the fiery dragons found in human folklore.

However, there were others—little, seemingly unimportant life forms, but significant beyond all telling. They lived in fear and hiding; they had learned to watch and listen and to run for cover. They were the mammals, waiting out their time on earth.

Three orders of mammals apparently existed late in the Triassic and continued into the Jurassic. Their fossils are found in the Rhaetic formation of Europe. In the late Jurassic the three orders were joined by two others. The five orders are known as the *Triconodonta,* the *Symmetridonta,* the *Docodonta,* the *Multituberculata,* and the *Pantotheria.*

The Mesozoic mammals are largely known by fossil teeth and jaw bones and by little else. Only a few skulls or adequate skeletons have been found. All of the creatures were small and all of them probably looked very much alike, perhaps resembling to some degree present-day rodents. The chief reason for separating them into distinct orders is the arrangement of their teeth.

Of the five orders, all but one died out. The *Pantotheria,* which may not have survived the Cretaceous, gave rise, however, to other orders which were the foundation stock of all the mammals of today. The first three named died out, perhaps by the end of the Cretaceous, without descendants. The *Multi-*

tuberculata survived through the Paleocene, the first epoch of the Cenozoic era, and then became extinct.

Throughout the Mesozoic the mammals remained little scurrying creatures—small life forms that had to cower and hide to keep out of the way.

But the mammals had a secret weapon. They were developing an ability that would allow them to live in a kind of world no reptile could face.

The secret weapon was internal heating—a complicated physical mechanism that always kept the blood at about the same heat level no matter what the temperature of the atmosphere might be. This made them fairly independent of external temperatures.

The birds had the same sort of mechanism, but no reptile had it—with the possible exception of the pterosaurs, and we cannot be sure of that. If they did, it probably was not as efficient a mechanism as was developed by the birds and mammals.

Without internal heating, the reptiles were dependent upon a fairly warm and steady temperature. They could not withstand either cold or extreme heat. The range of temperature in which they could exist was probably very narrow. They were sluggish in the chilliness of night and again during the midday heat.

Just possibly it may have been this very situation which made it possible for the mammals to survive. It is entirely probable that they learned to remain in hiding while the reptiles were most active, going out to seek their food only during those periods of comparative chill or extreme heat when their enemies were sluggish and not given to much hunting.

The mammals had another secret weapon, too, but as yet it was too insignificant to give them much advantage. This weapon was the capacity for intelligence, but it would take many more millions of years before it would develop to the point of becoming an evolutionary or survival factor.

15. THE CRETACEOUS

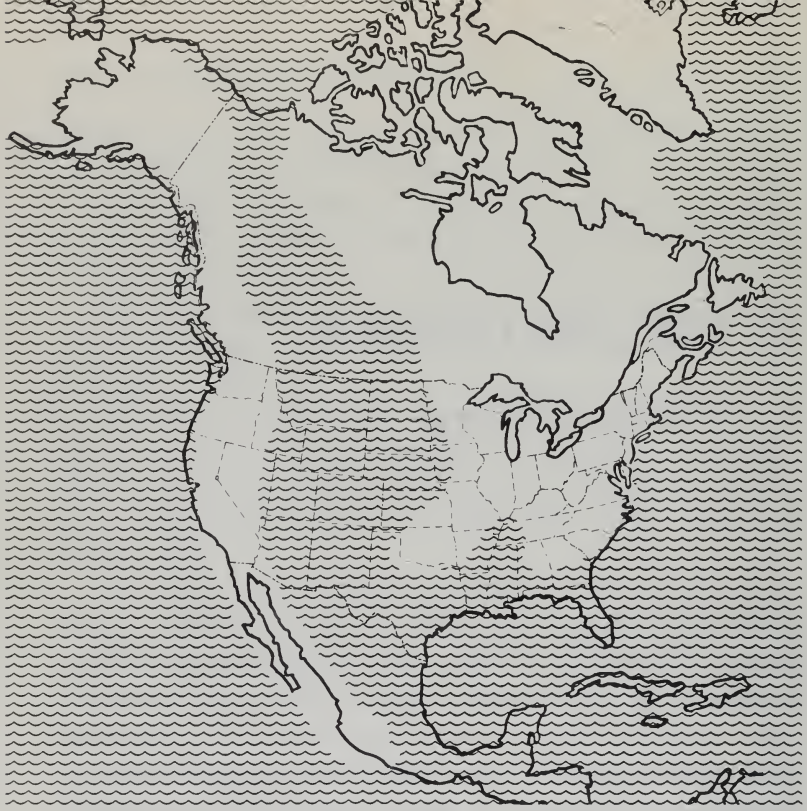
A Time of Dying

THE WORLD became more modern in the Cretaceous period. For the first time deciduous trees, the second kind of trees we have in the world today, began to spread across the landscape. And at the end of the period the hordes of dinosaurs and many other reptiles, for reasons still unknown, were wiped off the face of the earth in a time of dying. With the reptiles gone, there was now room for the mammals. They moved into the vacuum which was created by the disappearance of the reptiles, and the Age of Mammals began.

The Triassic and Jurassic periods had seen the decline of the epicontinental seas. Now, in the Cretaceous, they came back again, covering land areas which had stood dry for millennia.

As the period opened, erosion had so reduced all that remained of the old land of Appalachia that the eastern seaboard of North America lay substantially where it is today. During the greater part of the period, if not all of it, the entire southeastern coast of the United States was submerged, with the shallow sea reaching far inland.

Early in the period an epicontinental sea began to invade



LATE CRETACEOUS

the Rocky Mountain geosyncline, the water simultaneously creeping southward down the trough along the present valley of the McKenzie River and northward by way of Mexico. During the Early Cretaceous the seas slowly advanced, meeting, at the beginning of the Middle Cretaceous, in Wyoming. Once joined, the sheet of water spread east to form a large strait which divided the continent into two land masses. The sea spread as far east as Minnesota, Iowa, and Missouri. To the east of it lay a broad stretch of land, the low and stable interior of the continent which had persisted since Cambrian times, while to the west the strip of land between the epicontinental sea and the Pacific was narrow and mountainous.

Soon after this maximum inundation, the northern end of the Rocky Mountain geosyncline began to rise and emerge. The great interior sea was driven back upon itself. Spread over the central part of the Great Plains states, the sea was flooded by sediments washing into it, principally from the highlands to the west, until finally there was no sea, but a great, broad, swampy plain. In the province of Alberta, Canada, and in Mexico, coal beds were formed in some of these swamps. Elsewhere, fast-flowing streams formed vast deltas of mud and sand—and over all of this roamed great herds of dinosaurs, leaving tracks which to this day are preserved in stone.

The Mesocordilleran axis, which first had started to emerge in the north out of the old Rocky Mountain trough, continued to rise. The uplift moved south and east. Out of this restless movement the primeval Rocky Mountains were being born.

The upthrust is called the Laramide revolution, named from the Laramie range which forms the forefront of the mountains in Wyoming. The floor of the geosyncline, running the length of the continent from Alaska into Central America, was subjected to folding and thrust faulting and the ancient rocks reared up. This was no gentle uplift; it was a violent readjustment of the crust, reacting to long ages of pressure and imbalance. Crustal unrest during the last half of the Cretaceous took place throughout the world, but nowhere was it as violent or as profound and far-reaching as it was in western North America. The reacting forces there were so great that in many places the geology of entire areas was jumbled, older rock thrusting up and overriding younger layers.

The Laramide revolution did not take place all at once—nor did it affect all areas at the same time. It took place over the span of several millions of years and, despite its violence, long periods of quiet undoubtedly persisted in many areas. Even before the epicontinental sea had been restricted by the uplift at the northern end of the geosyncline, the sea floor may have

buckled in places as the stresses accumulated. Local anticlinal folds probably reared up out of the sea as islands, forerunners of the revolution yet to come. And there may have been repeated upthrusts in one area spread over a great space of time. In the Wasatch Mountains in Utah eight stages of deformation, occasioned by eight periods of thrust and uplift, have been recognized.

The easternmost boundary of the revolution is marked by the Big Horn Mountains and the Black Hills of South Dakota, outriders of the violence that raised greater mountain ranges farther west.

The thrust, in general, was from west to east, and in some instances the displacement caused by the eastward thrust measures as much as 35 miles.

During the crustal movements several huge batholiths, enormous underground wellings-up of molten rock, intruded themselves into the rising mountains. Some of them now lie exposed by subsequent erosion. The Sierra Nevada batholith is about 400 miles long and 80 miles wide. The Coast Range batholith is about 1,000 miles in length. In Idaho the eroded summit of an enormous batholith now lies exposed over an area of some 16,000 square miles.

It is unlikely that any batholith formed all at one time, in one great upsurge of molten material. Rather, each probably is the end result of repeated injections and upwellings of magma, one following another over a considerable length of time.

During much of the time that the mountains were building, the western highlands bore long chains of volcanoes, which were active much of the time. Ash from these smoking mountains was blown eastward as far as Kansas and Nebraska. Layers of ash are found in many of the Cretaceous shales of the Great Plains states.

At the time mountains were being raised in North America,

much the same thing was happening in South America. Since the Cambrian period, more than half a billion years back in time, the great Andean geosyncline had persisted. To the west of it high borderlands repeatedly rose and wore down, only to rise again. And all this time erosion had carried down into the steadily sinking geosyncline a perfect torrent of sediments off those western highlands. Now, in the last half of the Cretaceous period, the geosyncline began to fold and rise into a chain of massive mountains. The chain began east of Trinidad, off the present Venezuelan coast, swung westward into Colombia, and then trended south down the length of the continent. At its greatest extent it probably reached beyond Cape Horn, which is the present terminus of the continent.

The Antillean mountain chain, lying athwart the course of the Rockies and the Andes, was formed at about the same time. It followed the trend of the Greater Antilles and today

Fossil crinoids from the chalk beds of Kansas.

its course is marked by the chain of islands that swing north, flanking the Caribbean, off South America's northeast coast.

In Europe the epicontinental sea which had overlain large parts of the continent during the Jurassic withdrew at the end of that period, leaving the land dry except for the southern Alpine region. In the Cretaceous the waters advanced again, forming a wide-spreading gulf over southern England and France and extending through northern Germany into Poland and Russia. This sea was bounded on the north by the highland of Britain and Scandinavia and on the south by a land barrier which apparently reached from the south of Ireland into Czechoslovakia. In the Late Cretaceous the embayment expanded greatly and the water seems to have been far deeper than is the case with most epicontinental seas.

In the south of England and in France, the deposits laid down by the Cretaceous sea took the form of chalk. A microscope will show that the chalk is formed of skeletons of our old friends the *Foraminifera,* the minute sea creatures of many curious shapes which still are with us today. Over the millions of years that the sea lay upon England and France, trillions upon trillions of these animals had lived and died, their limy shells drifting to the bottom of the sea and building up thick layers of ooze. In time the ooze was turned into chalk. Today the chalk forms the white cliffs at Dover and appears in many other places, both in England and in France, along the English Channel. The name of the period is taken from the Latin word creta, meaning chalk, because the first strata of the period were studied along the channel separating southern Britain from the Continent.

In the late Cretaceous a broad general uplift of the land caused the seas to withdraw from most of Europe. But in the period itself it seems unlikely that there was any European mountain-building such as occurred in the two Americas. The broad uplift, however, set the stage for mountains yet to come.

In Africa all of the north, including the present Sahara Desert, was under water during most of the period. In the south there is geological evidence of three invasions by the sea and at different times both the east and west coasts were submerged.

In Australia the western half of the continent at times was under water.

In the Early Cretaceous the world's temperature seems to have fallen. Coral reefs were more restricted than they had been in the Jurassic period, a fairly reliable index of world temperature. Moreover, there is evidence that early in the period Australia's eastern high plateau was capped by glaciers which trended westward toward the sea. In the western part of the continent ice-striated stones, up to six feet in diameter, have been found scattered somewhat haphazardly. Apparently these stones were carried out to sea by icebergs breaking off the forefront of the eastern glaciers.

As the epicontinental seas spread over greater stretches of land later in the period, however, the temperature became mild and equable, the standard situation for an oceanic world. Upper Cretaceous rocks, even in the higher latitudes, bear abundant fossils of land plants now generally restricted to tropical and subtropical climates. In Alaska grew palms, figs, and cycads. In Greenland the Cretaceous beds yield fossils of figs, breadfruits, cinnamon, laurels, and tree ferns. Dinosaur fossils are abundant throughout the Canadian province of Alberta and in Mongolia. Only recently the fossil skeleton of a dinosaur was found on the island of Spitsbergen. No icecap existed over Greenland, as is the case today, and the Arctic Ocean probably was free of ice, as well.

The deciduous trees were newcomers in the Early Cretaceous, but before the end of the period they dominated the landscape as they do today.

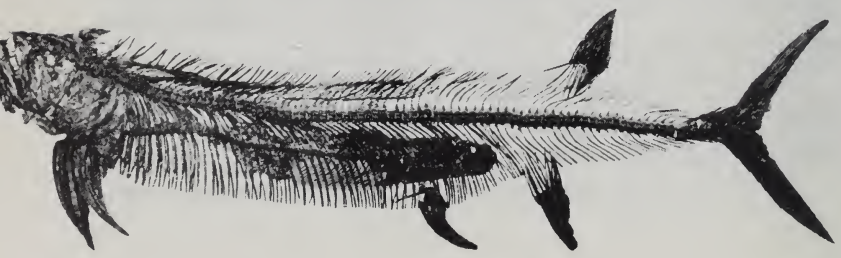
Deciduous trees are those which drop their leaves in the

fall and grow new leaves in the spring. Among the oldest of them are the magnolia, fig, sassafras, and poplar, all of which appear as fossils in Lower Cretaceous beds. By the middle of the period these species had been joined by birches, maples, beeches, walnuts, planes, oaks, tulip trees, breadfruits, sweet gum and ebony. A number of deciduous shrubs—laurel, ivy, hazelnut and holly—also had appeared by this time.

Intermingled with the deciduous trees, of course, were evergreens, but these more primitive trees no longer dominated the landscape as they had for long ages past. One new kind of evergreen, the sequoia, made its first appearance in the Cretaceous, but none of them grew as large as California's giant trees of today. Also still conspicuous were the cycads. Their short, stocky trunks are found as fossils in the lower layers of the Dakota sandstone group in the Black Hills of South Dakota and in Colorado in the Mesa Verde sandstone, which dates to the end of the period.

Most deciduous trees belong to the angiosperms, the highest order of the plant kingdom, which today includes all flowering plants. Second only to the spread of plant life out onto the land, the development of the angiosperms is the most significant advance in the entire evolution of plants. The angiosperms provide nuts and fruits, grasses, grains, fodder—practically everything that man has cultivated. And all those pretty flowers out in the garden also are angiosperms.

Late Cretaceous fossils show fish within a fish.



The resting stage of the angiosperm, represented by the ripening of seeds and the dropping of foliage, clearly seems to be an adaptation to seasonal climates. Probably the evolution of these plants took place on highlands where the climate was cool and where, either because of the cold or because of drought, the growth was seasonal. However, not until the angiosperms migrated to the lowlands, where sediments were being deposited, was it possible for them to leave a fossil record. Bearing this in mind, it seems quite possible they may have been growing in some abundance in the highlands in Jurassic times and may even have evolved as far back in time as the Triassic period.

In Cretaceous times the dinosaurs were in their greatest glory. There were more of them than there had ever been before, and they began to go in for specializations that turned some of them into walking nightmares.

The Cretaceous dinosaur most readily recognized by the general public is probably *Tyrannosaurus rex*. A huge and fearsome beast, he has been much used by writers of fiction who lay their plots in the distant past or in some fictional "lost land," and the very size and seeming ferocity of this great reptile has captured the public imagination.

Tyrannosaurus rex was big. He measured about 47 feet in length and, walking on his hind legs, stood some 19 feet tall. A stocky brute, he must have weighed close to 20 tons. There seems little question that he was the largest flesh-eater that ever trod the earth. His skull was more than four feet long and was mostly jaws armed with terrible teeth.

There is no question that he was a flesh-eater, and he may have been a killer when he had the chance. But for all his size and strength, he probably was clumsy. His very weight and ungainly size would have robbed him of the agility which a killer needs, and there are many paleontologists who believe he was not the killer he is so often advertised to have been.

It is believed more likely that he was a scavenger, living on carrion. He may have prowled about, picking up whatever he could find or driving other hunting beasts from the kills they made.

Tyrannosaurus rex belonged to a group of dinosaurs which included many others which looked a great deal like him. But they all ran smaller than did old rex himself. Because of their smaller size they may have been the real killers of this particular tribe of dinosaurs.

Despite the fact he is widely-known, *Tyrannosaurus* did not leave much evidence behind him. To date one complete skeleton has been found, together with two skulls and other scattered bones and teeth.

In addition to *Tyrannosaurus* and his relatives, another family of hunting dinosaurs inhabited the Cretaceous. They are known as coelurosaurs and were smaller than *Tyrannosaurus,* and more agile.

Not all dinosaurs were ferocious, or even had the look of ferocity about them. The duck-billed dinosaurs, for example, were strangely docile-appearing beasts. They are called duck-billed because of an elongation and a widening of the jaws to form what appears to be a typical duck bill. While they traveled on their hind legs, their front legs had not become as atrophied as those of *Tyrannosaurus* and some of the other hunting dinosaurs, so that occasionally, when the situation demanded, they could drop on all fours. They probably also were able to sit down, supported by their haunches and their tail, something that old *Tyrannosaurus* never would have been able to achieve.

A few fossils from Canada indicate that at least some of the duckbills had webbed hands and feet and that they may have been powerful swimmers. The long tail, somewhat flattened at the sides, would have been useful in propelling the animal in water. The evidence, however, seems to be that they

Duckbill dinosaurs lived in area that is now Wyoming.

spent at least as much time on land as they did in water. Their tracks are plentiful in many Cretaceous rocks. Apparently they fed on vegetation growing along the margins of marshes and lagoons, and it may be that they used their swimming ability only as a protective device. Trapped by a hunting dinosaur or a band of hunting dinosaurs on the edge of a lagoon, they could have found safety in the water.

Many of the duckbills sported fantastic crests atop their skulls, and in most cases the nostril openings, which ordinarily would have been placed somewhere to the forefront of the upper jaw, had been moved upward to the crest. Some of the crests were fantastically shaped, while others were little more than a high dome on the head. In all cases, no matter what

***Triceratops* and *Tyrannosaurus rex* square off for fight.**

the shape, the interior of the crest was a thin-walled chamber of bone with the nostrils opening into it. Some paleontologists have suggested that the chamber may have been used for the storage of air when the animal was under water. Such a device might have enabled it to stay under for a considerable length of time while it grubbed for fodder on the floor of the lagoon. Another suggestion is that the hollow crests were resonating chambers, which enabled the animals to produce sound. Most likely explanation, however, is that the chambers served the purpose of a nose, affording a large surface area for the mucous membrane which contained olfactory nerve endings, giving the animal a sense of smell more acute than can be well imagined. Being without any effective defense against attack, a keen sense of smell would have afforded the duckbill a large measure of protection by warning it, well in advance, of the approach of predators. And such a sense of smell might, as well, have been useful in locating vegetation for which the animal had a particular liking.

Another dinosaur which resembled the duckbill in appearance is popularly called the bonehead since its crest was a solid mass of bone. Just what purpose such an arrangement might have served, no one pretends to know.

One of the most fantastic of the dinosaurs, which really did not look as one expects a dinosaur to look, was the ankylosaur. It appears, when one looks at a reconstruction of it, to be a cross between a turtle and a horned lizard. The body is shaped somewhat like a turtle's body, with a dragging tail such as no turtle ever had. The entire body was covered by heavy plate armor. Most of the ankylosaurs reached a length of 15 to 18 feet, but were built low to the ground. Some of them had spikes projecting from the edge of the armor plate, and in some species the tail was spiked as well. The head was small and the teeth were weak. No killers, they lived on plants. But their heavy armor would have given them some protection against predators and such a heavy tail, spiked or plain, would have served as an effective weapon against an attacker.

Triceratops was another common dinosaur, only one of the many horned species. The name *Triceratops* means "three horns on the face," and the three horns were backed by a wide bony frill set behind the creature's eyes and covering the neck. One horn was set over each eye and another on the tip of the snout. The bony frill and the three horns represented formidable defense equipment so long as the animal could manage to keep facing an attacker.

Triceratops measured about 20 feet in length. His body was bulky and he carried a short tail. His head was about five and a half feet long. The jaws carried specialized teeth, suitable only for chewing up fodder, but the upper jaw ended in a sharp, recurved beak that probably could be used effectively against an enemy.

This account covers only a few of the more typical of the

Cretaceous dinosaurs. A book many times larger than this one would be required if one were to attempt to tell the entire story of the dinosaurs.

We know of hundreds of species of dinosaurs. There undoubtedly were many others of which no fossil record has been left. They ranged in size from *Tyrannosaurus* and the sauropods down to creatures the size of dogs. Over the millions of years covered by the Mesozoic era, evolution produced and discarded thousands of different forms of these strange creatures.

One thing more, perhaps, needs to be said about the dinosaurs.

They were incredibly stupid brutes. And no wonder—they had scarcely any brain.

Paleontologists measuring the brain cases of dinosaurs have found that the brain of the biggest of them was no larger than the brain of a cat. And that, perhaps, is giving the dinosaur the benefit of the doubt, for in determining the brain size the paleontologists measured the dimension of the brain case, and it is unlikely that the brain would have filled that entire space.

In mammals the size of the brain increases with the size of the body, although the efficiency of the brain seems to have something to do with the relative size of the brain and the body. The elephant has a brain four times the size of a man's brain, but the brain of a man is much larger in proportion to the size of his body than is the brain of an elephant.

This rule didn't hold true with reptiles. *Tyrannosaurus rex* had a brain that was not a great deal bigger than that of some of the much smaller dinosaurs.

It is believed that the reptile brain made no provision for intelligence, and was no more than a sense receptor and a motor organ. It sensed danger and warned its owner to get away from it; it sensed food and directed its owner to it. But the dinosaur probably had little, if any, memory, and it certainly did not think or reason, even at the lowest level. It ate when

it was hungry, it rested when it was tired; it responded only to its creature needs.

In addition to the tiny brain, many of the larger dinosaurs had an enlargement of the spinal cord in the pelvic region and sometimes another similar enlargement in the region of the shoulder. These enlargements, however, were not brains, although in some cases they were as large as or larger than the brain. It is believed that they were no more than enlarged nerve centers necessary for the proper functioning of the creature's body—in the case of the one in the pelvic region, with the functioning of the hind legs and the tail. Much the same thing can be found today in the ostrich, which has an enlargement of the spinal nerve in its pelvic region to compensate for the enlargement of its legs for rapid running.

In the Cretaceous the pterosaurs, the flying reptiles, were less various and perhaps not as numerous as they seem to have been in the Late Jurassic, but what there were of them were larger and more spectacular. The largest of them so far known, *Pteranodon,* had a wing spread of 23 feet, but its body was no larger than that of a wild goose and its hollow bones were so delicate that its weight, as compared with its size, must have been very little. It has been estimated that it may not have weighed much more than a pound.

Remains of these creatures have been found in the Niobrara chalk in Kansas, in locations which must have been some distance from the shore of the ancient sea which at that time covered the area. Apparently *Pteranodon* in many ways resembled the modern albatross, able to soar over the ocean's waves for incredible lengths of time. Unlike the pterosaurs of the Jurassic, the Cretaceous flying reptiles were toothless. Their horny beak was like a bird's.

While a number of birds may have lived during the period, their fossil remains are rare. The best known is a large, flightless bird, *Hesperornis regalis,* also found in the Niobrara chalk of

Kansas. It appears that this giant bird, like the penguins of today, has adapted so perfectly to life in the sea that it had lost its ability to fly. Only vestiges of wings are present in the fossil skeletons, and the legs are seen to have been so articulated as to form efficient swimming organs. Because of this, it would have had an awkward time on land. All the fossils of this species, like those of *Pteranodon,* have been found in deep marine deposits. *Hesperornis* stood (if it ever stood) four and a half feet tall and, unlike most birds, its long bill was armed with teeth.

Several of the modern orders of birds—ducks, grebes, and pelicans—are known to have lived during the Cretaceous, but their fossil remains are only fragmentary.

Two new orders of mammals made their appearance in the period—the marsupial, or pouch-bearing animals (the kangaroo and opossum are marsupials), and the insectivores, to which today's moles and shrews belong. The five orders which were known in the Jurassic survived into the Cretaceous period, but all except the multituberculates died out before the period ended. The multituberculates died out, in turn, in the Cenozoic period, leaving no descendants. It is probable that the marsupials and the insectivores were offshoots of the pantotheres. This belief arises from the fact that a study of their teeth reveals a striking similarity to the later mammals.

It is likely that in the Cretaceous mammals were more numerous than the fossils remains that have been found would indicate. They had persisted for millions of years and had found a niche in the Mesozoic ecology which allowed them to live on. So long as the reptiles dominated the scene, however, and until cereal grasses and fruits became common, their opportunity to expand and develop was strictly limited.

In the Cretaceous the invertebrates had become more modern. Many of the more specialized and fantastic forms had died out. The brachiopods, which at one time had existed in

untold numbers, were no more common than they are today. Corals were plentiful in Europe, but not in North America.

There are few fossil insects from the Cretaceous, but it would seem fairly safe to assume that all the modern forms had developed by this time and had settled down into the comfortable niches of existence which they still occupy today. Cretaceous insects undoubtedly had adapted, probably early in the period, to feeding upon the nectar of the flowering plants which first appeared in the period. If so, they had assumed their important role of cross-pollenization.

By the end of the Cretaceous the land masses of the world, as the epicontinental seas withdrew, had generally assumed the shapes and positions which we know. The world was slowly settling down to its present form.

And as the period came to a close, something else happened as well—most of the reptiles disappeared. No one knows what happened to cause this great dying out. There has been, and still is, a vast amount of speculation, but no certain answer.

But the results of what happened can be read in the rocks. In a comparatively short time the entire world of dinosaurs, and many of the other reptiles, was swept away. Cretaceous rocks have dinosaur fossils. No rock after the Cretaceous period has as yet yielded a single fragment of dinosaur bone. Not a single dinosaur, apparently, survived the close of the period.

The extinction of the reptiles may not have been as abrupt as the evidence might make one think. Geologically, it was abrupt. When one uses a million years as a scale of measurement, it was accomplished in the winking of an eye, but measured by time as we experience it, the end probably did not come so swiftly. It may have taken some thousands of years before the last of the dinosaurs and their relatives died out.

A few thousand years, which may seem a long time to us, is less than a paragraph, scarcely more than a sentence, in the book of rocks which records the history of past ages.

***Tylosaurus*, a large swimming lizard, attacks marine turtle.**

Extinction, as well as origin, is an evolutionary feature. It does not happen without reason. And it has a purpose. If evolution did not operate to bring about the extinction of certain forms of life to make way for new, the earth long since would have become clogged with a fixed and static life. But extinction of one form of life makes way and leaves room for another form to arise. This is what happened at the end of the Cretaceous. The reptiles became extinct and the mammals took their place.

Extinction generally comes about as the result of a life form being unable to adapt to changing conditions. In formulating reasonable theories to account for the disappearance of the dinosaurs, it is here that we must search for an answer.

The Cretaceous world was a world of change. In the Permian a worldwide orogeny resulted in the introduction of seasons and of locally harsh climatic conditions. In the Cretaceous the upthrust of mountains along the western rim of the North and South American continents, and the uplift elsewhere in the world, may have resulted in a general lowering of the earth's temperature. Such a change would have been gradual, but had it gradually grown colder, there would have come a time when the reptiles no longer could exist. Reptiles, even those which

still remain on earth today, can live in only a very narrow temperature range.

If the climate grew colder at the end of the Cretaceous, the dinosaurs were doomed. The same doom would have faced them if, even for a brief period, some set of circumstances had existed which warmed up the climate beyond the norm. The dinosaurs could have coped no better with extreme warmth than with cold. Either would have spelled their end.

There is no positive evidence that either of these things happened on a worldwide basis. There is nothing that tells us that the climate became either warmer or colder. But these are two factors that must be taken into consideration, for either of them could supply the answer.

Another reason that has been advanced for the extinction of the reptiles is the change which came about in the vegetation of the earth during the Cretaceous period. Modern forests replaced the primeval trees and plants which for millions of years had supplied fodder for the herbivorous dinosaurs. If the plant-eating dinosaurs were unable to sustain themselves on this new type of vegetation, they would die out. When they were gone, the carnivorous dinosaurs, which depended upon them for food, would starve to death.

But once again, there is no evidence for such a hypothesis. The dinosaurs apparently had survived for a long period of time in a world in which the modern forests were dominant. And while the new situations might have affected the larger herbivores, they probably would not have affected the many smaller reptiles which did not require the vast tonnages of food that the big fellows did. In that case the larger reptiles would have become extinct because of lack of forage, while the smaller ones survived. But this is not the case. None of them survived. There was no distinction between small and large, plant-eaters or meat-eaters, hunters or hunted. Nearly all died out.

It has been suggested that the reptiles may have been wiped

out by an epidemic which swept the Cretaceous world. This is a credible theory if one were considering only two or three of the many kinds of dinosaurs. If only old *Tyrannosaurus,* along with two or three of the other species of dinosaurs closely related to him, had been wiped out, this explanation would seem possible. Most epidemics are very specific and operate within very narrow biological limits. They can wipe out species. But this is not what happened in the Cretaceous. Not just one species was wiped out, but all of them.

Still another theory, which has little to support it, is that competition from mammals may have spelled the end of the reptiles.

Most students of paleontology believe, however, that the mammals were in no position to even attempt competition with the mighty beings that strode across the land. They had to stay in hiding and in waiting, until the enemy was gone. But when that did happen, they would have come out, unmolested, and taken over the land in which they had scurried for so long beneath a pall of fear.

There is, as well, the related theory that while the mammals may not have been able to compete to a point where they finally crowded the dinosaurs off the earth, they might have brought about their extinction by raiding dinosaur nests and eating dinosaur eggs.

This undoubtedly did happen. Perhaps many a mammal made a square meal off a nest of dinosaur eggs. Egg stealing may have been a very slight factor in contributing to the disappearance of the dinosaurs, but it could not be the entire story. The dinosaurs laid billions of eggs each year. It seems against all reason that the mammals could have made such inroads upon them as to cut down the dinosaur population by any appreciable percentage.

Another theory involves what is known as racial senescence. This theory views the existence of a species in the same light

as it does an individual life. As in the case of an individual, it says, races come to birth, pass through childhood and early adulthood, reach middle age, and decline through old age to their deaths. This, the theory suggests, is what happened to the reptiles. As a race, they simply became old and died.

But there is little or no evidence which would bear out such reasoning.

There are other theories bearing upon the extinction of the reptiles. But as the length of the list increases, the theories become more and more difficult to support.

In all this fog of theories, however, there is one piece of evidence which may give a clue to what happened.

In at least one area of the earth, evidence has been found of the specific conditions under which they disappeared. This area is the state of Montana and the work has been done by Dr. Robert E. Sloan, geologist at the University of Minnesota.

Digging east and south of Fort Peck dam, Sloan found that slightly more than 60 million years ago Montana was covered by a subtropical rain forest. In this forest lived dinosaurs.

A study of the strata shows that over the course of a million years the rain forest disappeared and was replaced by conifers and deciduous trees living in a humid temperate zone. In the million years during which this change took place, Sloan estimates that the climatic boundary moved south 1,000 miles.

As the climate grew colder the dinosaurs that had lived in the rain forest disappeared and were replaced by an invasion of mammals from the north. Apparently the dinosaurs moved south to keep pace with the warmth, while the northern mammals followed the slow southward creep of the climate and conditions to which they were accustomed.

Sloan does not claim that he knows what happened to the dinosaurs all over the world. He has, however, determined what sort of a world existed in Montana, and presumably much

of the Northern Great Plains, at the time the dinosaurs disappeared.

The fossil records show that the first of the dinosaurs to disappear were the ankylosaurs, the large armored creatures which somewhat resembled turtles. Next to go was our old friend *Tyrannosaurus. Tyrannosaurus* teeth were found by Sloan in strata some 100 feet below the boundary line between the Cretaceous and the Paleocene, which he places tentatively at the division between the Hell Creek and the Tullock formations. The other dinosaurs persisted up to the very edge of the hypothetical boundary, but evidence of them dwindled as the investigation moved upward in the strata.

A radioactive dating of 63.2 million years was obtained from a coal bed in the boundary between the Hell Creek and Tullock formations. This means that the coal bed was formed 63.2 million years ago. The figure is sound except for the usual two per cent margin of error either way.

A few mammals, among them the opossum, co-existed with the dinosaurs in the rain forest. The new tribes of northern animals which moved into the area with the southward regression of the climatic zone, seem to represent a fairly large population of mammals which for some time had been living in the north, beyond the range of the dinosaurs. How long they may have lived there, Sloan will not even try to guess.

The change in climate apparently came about as the result of the shrinkage and final disappearance of Cretaceous seas.

While there is no evidence (and may never be) of when or where the last dinosaur died, the evidence from Montana shows that the beasts were pushed southward by cooler temperatures. With their range restricted, they were staring extinction in the face. So far as the western hemisphere is concerned, they may eventually have been crowded down into the narrow wedge of Central America.

16. THE CENOZOIC

The Age of Mammals

WITH THE CLOSE of the Cretaceous period, we enter upon the last era of geologic time, the Cenozoic. It is still continuing; we are living in it now.

The Cenozoic generally is dated from about 63 million years ago. As a rule it is not divided into periods, but into six epochs. Some people, however, believe that it should be divided into two periods, the Tertiary including the first five epochs and the Quartenary the last epoch. And there are some people who would divide it into seven epochs, dating the seventh from some 10,000 years ago, with the retreat of the last glaciation, and calling it the Recent.

The first of the six epochs is the Paleocene. The second, the Eocene began about 58 million years ago; the Oligocene about 36 million years ago; the Miocene 25 million years ago; the Pliocene 13 million years ago, and the Pleistocene a million years ago. Some recent studies, however, may be about to push the beginning of the Pleistocene back to about one and a half million years ago.

The Cenozoic is an unusual stage of the world's history. We are living in a far more interesting and picturesque time

than the world has generally known. The continents are larger than usual and as a result we have definite climatic zones and seasons, something the world has not always had. The world's highlands are more extensive and the mountains loftier than has generally been the case. Throughout much of its history the earth has tended to be rather flat and monotonous. But now we have plentiful and varied scenery to enjoy.

While North America and the rest of the continents had largely assumed their present position and size by the end of the Mesozoic era, there still remained some readjustments before the world became as it is today.

The Atlantic and Gulf coasts of the United States remained partially submerged, with bays from the Gulf coast sea extending deep into the continent, until the Oligocene. From time to time in the Early Cenozoic, small embayments extended into parts of California, Oregon, and Washington, and for a brief time a sea covered part of the northern Great Plains. But in comparison with other periods, North America remained high and dry. At no time during the Cenozoic did water ever cover more than 10 per cent of the continent.

Yet, for its comparatively brief existence, the sea that covered the Gulf states left behind it an impressive amount of deposits. Oil wells drilled to 25,000 feet have not reached the bottom of the Cenozoic rock. It is believed that the Cenozoic strata in this area of the country may reach as deep as 30,000 feet.

At the beginning of the era Florida did not as yet exist. It is believed that a submarine bank covered by shallow water may have stood in the Early Cenozoic where Florida now lies. The bank may have stood above water at various times; geologists believe that a long, low island existed along the central part of the present state during part of the Miocene, although the peninsula may not have become permanently established until much later.

During the Pleistocene, currents running along the eastern

EARLY CENOZOIC

Atlantic shore spread deposits of fine quartz sand southward along the coasts of South Carolina, Georgia, and Florida, creating beautiful sand beaches. It is to this that Florida owes its present-day resort business. A similar layer of fine sand was spread at about the same time along Florida's west coast, forming a belt several miles wide as far south as Tampa.

The Mississippi river system apparently dates from the Early Cenozoic, although the present delta at its mouth was not formed until the Pleistocene. Older deltas may lie buried beneath the debris which the stream has carried for millions of years. Geologic evidence shows that streams were converging toward the trough of the present Mississippi lowlands as early

as the Paleocene. At that time it appears these streams were dumping their loads of sediments as far north as Cairo, Illinois, probably at the time when the deep embayment from the sea that covered the Gulf state thrust far into the continent.

As the Cenozoic dawned almost all trace of the primordial Appalachian mountains had been wiped out by erosion. A few high hills may still have remained in eastern Tennessee and North Carolina and in parts of what is now New England. But aside from this, it is likely that at the beginning of the Cenozoic most of the eastern United States stood not too high above sea level.

The present Appalachian mountains were not formed by any new mountain-building activity. What happened was that the entire region was uplifted and the mountains which we know today were formed by erosion sculpturing the highlands. The uplift was not general but came in a series of thrusts. As the land arose, the present continental shelf, which in places may have been emergent during the early part of the period, was depressed and tilted downward beneath the sea. With its disappearance beneath the waves, the last trace of ancient Appalachia was gone.

In the west, the mountains which had been raised toward the end of the Cretaceous period by the Laramide revolution still were standing at the beginning of the Cenozoic. But as the millennia passed these mountains also were eroded away, most of the sediments draining into the basins which lay between the ranges. As the mountains wore away, the basins were filled with sediment. By the Late Oligocene the first generation of the Rocky Mountains had disappeared and where once they'd stood there was a level plain.

In Miocene and Pliocene times a broad uplift buckled the entire region into a low arch hundreds of miles across. The uplift correlated in time with the thrusting-up of the Cascade ranges farther west, and the crustal movement is known as

"Old Faithful' geyser is a modest holdover from more spectacular days of volcanic activity.

the Cascadian uplift. The slow uplift continued intermittently until finally a maximum elevation of 10,000 feet or so had been reached along the present Continental Divide. This was much the same as what had happened a little earlier in the Appalachian region, but on a somewhat grander scale.

With the uplift of the land, fast-flowing streams began the work of erosion. They deepened their valleys and began to excavate the sediment-buried basins and in places may have exposed the bases of the mountains formed in the Laramide revolution. Thus the present Rockies, while they owe their height to the slow and gradual uplift that arched up the land, owe their relief to the work of running water. Many of the more spectacular canyons found in the west today are of fairly recent origin. It is likely the Colorado River did not exist until after Miocene times, yet since that time it has carved out the

Grand Canyon. At one time, some millions of years ago, the canyon walls were much higher than they are now. Since then the land has been cut down by erosion and the walls, in consequence, are lower.

The western part of North America continued restless until modern times, and it is entirely possible that the crustal shifting is not finished even now. The greatest crustal movements in California appear to have occurred not more than half a million years ago.

This restlessness was accompanied in many cases by volcanic activity on a scale which had not been approached anywhere in the world since Precambrian times.

Great lava flows during the Miocene covered an area in Washington and Oregon larger than all of New England. The Columbia plateau is one huge block of lava poured out at that time. In the Yellowstone area huge volcanoes reared up in the Eocene and darkened the skies with their ash. The geysers and hot springs which today are tourist attractions in that area supply good evidence that the volcanic heat still is there, a holdover from more spectacular days. The White River sediments, which form fantastic landscapes in the Badlands of South Dakota, are made up of volcanic ash. Much of the ash may have come from volcanoes in the Black Hills area.

On a steep bluff overlooking the Lamar river a few miles above its confluence with the Yellowstone river, in the northeastern corner of Yellowstone National Park, erosion has uncovered 27 layers of petrified trees, dating back to the days of volcanic action in the Eocene.

The story of what happened is not too difficult to puzzle out. When the first outburst of volcanic action came, a forest which was growing on the plain below the great volcanoes that stood to the north and east was buried by the ash and other volcanic debris. Finally the volcanic action ceased and the land stood gray and desolate. But in time seeds took root

Twenty-seven layers of petrified forests have been exposed by erosion of mountainside in Yellowstone Park.

and grew, and once again the area was covered by a forest. In turn the volcanoes became active once again and the second forest was buried underneath the ash.

In the meantime, mineral-bearing water beneath the surface turned the buried tree trunks into stone, leaving a record of what had happened.

The face of the bluff above the Lamar measures about 1,200 feet in height, and holds the petrified remains of 27 different forests, each in turn having been buried by the ash of as many major eruptions. Unlike the petrified forests of the Painted Desert, the tree trunks on the Lamar bluff stand erect, still rooted in the soil, exactly as they stood when they were buried. In the Arizona petrified forests the fossil logs do not lie in their original locations, but are found where they were deposited by some ancient river which in flood times had carried them far downstream.

While the bluff above the Lamar river shows the petrified forest of the Yellowstone to the best advantage, the fossil forest actually covers an area of more than 40 square miles.

In South America the history of the Andes Mountains pa-

rallels that of the Rockies in many ways. They arose at the close of the Mesozoic era, and during the first half of the Cenozoic were extensively eroded. By the middle of the era they probably had been leveled. Then in the Pliocene and the Pleistocene they were elevated once again and sculptured by erosion.

The Alpine-Himalayan system of mountain ranges, which extends from western Europe into Asia, was raised in the Cenozoic. The first faint beginnings of the Alps can be dated back to Jurassic times when compression from the south caused two or three great folds of rock to hump up. But despite this, the region as a whole remained under water during most of the Cretaceous period. At the close of the Cretaceous some further uplift occurred, but apparently to a small degree only. The seas came back in the Cenozoic and remained as bays between the rising folds until the Oligocene epoch. Then, finally, after many years of notice that mountains were about to rise, the mountains did arise. The land heaved up out of the sea and rode northward across the edge of that ancient geosyncline still marked by the Mediterranean sea.

Ahead of this northward thrust lay a lowland which is now the Swiss plateau. During the Late Oligocene and Miocene times, sand and coarse gravel from the rising mountains built up the lowland as a deep layer of sediments. Some marine strata in the rocks show that occasionally and for short periods the sea again washed across the land.

In the Pliocene epoch new crustal thrusts from the south pushed the mountains north again, buckling up the Jura folds which today form the northern forefront of the Alps. Hardly had this new crustal movement come to a halt than the region underwent a less violent general upheaval which further raised the new mountains and finally closed the gates of southern Europe to the sea. The culmination of this uplift probably came sometime in the Pleistocene.

The history of the Carpathians and the Himalayas is about the same as the history of the Alps. In the southern ranges of the Himalayas marine formations from the Eocene are found at an elevation of 20,000 feet, testifying to the tremendous uplift which boosted up the peaks.

During the latter half of the Cenozoic and into the Pleistocene, the crustal upheavals which raised the present mountains of the world went hand in hand with tremendous volcanic activity. We have already noted what happened in North America. But this was only one phase of a long period of volcanism.

In Central America, the Antillean islands, and the Andean plateau of South America, great outpourings of lava spread across the land. Large basaltic flows occurred in the lands of the North Atlantic—in eastern Greenland, Iceland, northern Ireland, northwest Scotland and the Orkneys. In the great rift valleys of Africa massive volcanoes spouted fire and smoke. During Pliocene and Pleistocene times a ring of fire flamed around the rim of the Pacific, with active volcanic chains erupting in Alaska, Japan, and the East Indies.

When the Cenozoic era began the world had a temperate climate. If the speculation that the reptiles died out because of a change in climate is correct, there must have been, at some time on the boundaries of the Mesozoic and Cenozoic, a period of unusual weather. If so, it was of relatively short duration, for during the early epochs of the new era the climate was warm and moist.

Subtropical trees grew over much of the United States. Palms and alligators ranged as far north as North Dakota. The climate there at that time would appear to have been about the same as it is in Florida or Louisiana today. North of the subtropical belt a moist temperate climate existed at high latitudes, in Alaska, Greenland, Spitsbergen and northern Siberia. Cycads, magnolias, figs and giant redwoods grew far north. The climate not only was warm and humid, but uniform

as well. The mountains as yet were not large enough to interfere with the normal wind patterns.

After Eocene times, however, a creeping cold set in. A gradual southward migration of the various plant assemblages can be traced in the fossil record. The cooling of the climate became marked in Pliocene times and culminated in the world-wide glaciation of the Pleistocene epoch.

In the Miocene the rising mountains in the western part of the United States grew lofty enough to change the rainfall pattern. The prevailing westerly winds dumped their loads of moisture on the western slopes of the mighty ranges, with the result that there was little, or no, precipitation to the east. It is from this time that we can date the deserts and the general aridity of certain parts of the western United States.

At the beginning of the Cenozoic only the turtles, the lizards, the snakes, and the crocodiles survived from that vast and varied assemblage of reptiles which had dominated the earth for so many centuries.

Now the way was open for the mammals to take over, to move in and assume the place that had been held by the reptiles for so long.

The mammals, to start with, were small and unimpressive. They were short-legged and walked flat upon the soles of their feet. They had 44 teeth, of which all but the canines were short-crowned. They were long-faced, their jaws exceeding their brain case in size. All of them seem to have sported a long tail. Their brains were small; their intellect was of the lowest order.

But now, given room and opportunity, the mammals began to develop.

The first common trend of development was in the matter of size. The Eocene ancestor of the horse was the size of a fox, that of the camel no larger than a jackrabbit; the early elephant was no bigger than a hog. And in that ancient day

a squirrel-sized half-ape was the forerunner of the human race. As the years went on the mammals grew larger, some of them growing to outlandish sizes. But these oversized creatures all died out; they were the victims of over-specialization.

Another developmental trend was the specialization of the brain and the growth of intellect. The development of the brain entailed not only an increase in its size, but likewise an increase in size in relation to the body of its owner. In many species the growth and development of the brain was disproportionate, featuring a greater growth of the cerebrum, which is the seat of memory and of reason. In this area, however, development was uneven among the species. The area increased considerably in size among a number of the mammals, notably man. In others, such as the shrews and the opossums, little growth resulted. The shrew and the opossum are not a great deal, if any, smarter than they were to start with.

Tooth specialization began to develop early among the mammals. You may remember that the basis upon which the mammals of the Mesozoic time were divided into orders was the differentiation of the teeth. Once the way was clear for the mammals to develop fully, tooth specialization went on apace. In the more primitive animals the cheek teeth had sharp piercing or shearing cusps, but were low-crowned and attained their full growth in the animal's early life. Later on, however, once grass appeared and furnished food for grazing animals, this simple arrangement was greatly modified. Grass contains an appreciable amount of silica, an abrasive material. Obviously, such a diet would wear a primitive tooth away. So the grazing animals developed large and high-crowned teeth which continued to grow throughout the animal's life. The teeth of such animals has enamel deeply folded into the crown, so that even after the tooth is worn, sharp ridges still remain, retaining a good grinding surface. And the slow, continual growth of the teeth insures that the teeth never will be entirely worn

down as might be the case with an unspecialized tooth.

The carnivores, or meat-eaters, developed large canines for holding prey and for tearing flesh, and narrow, shearing jaw teeth. The greatest specialization in canine teeth came in the stabbing cats, commonly called the sabre-tooths, which developed huge fangs, using them to stab their prey.

Some mammals did not go in for tooth specialization. Hogs and men, for example, show little specialization.

Another, and very important, specialization was in the feet and limbs. The first mammals had short legs and walked flat-footed, on the soles of their feet, as men and bears still walk. But once given living space and an opportunity to adapt to an unrestricted environment, the mammals forthwith proceeded to carve out environmental niches they could claim as their own, and their limbs and feet developed to fit these particular niches. The tree-dwellers developed prehensile hands with opposable thumbs, the better to grasp and climb. The hand development was accompanied by the development of a great toe on the hind feet. Carnivores developed claws for seizing and holding. The herbivores, the grazers, were the natural prey of the carnivores, and were dependent on their fleetness for survival. They had to be able to elude or outrun a carnivore; if they failed, they died. So the herbivores developed limbs to make them fleet of foot. They underwent a specialization which literally put them on their toes. They lost all toes but one, and that toe became a hoof. Their legs grew slim and long and they developed exceptionally powerful muscles to drive those long and slender legs.

Many of the mammals, of course, over-specialized, and accordingly died out. But over-specialization among the mammals does not seem to have been carried to the extremes one notes among the reptiles of the later Mesozoic.

Once relieved of the restricting pressure of the reptiles, the mammals developed rapidly. At the end of the Cretaceous only three mammalian orders are recorded in the fossil-bearing

rocks. These were the multituberculates, the marsupials, and the insectivores. By the end of the Paleocene other orders that had arisen included the primates, the rodents, the carnivores, the condylarths, and the amblypods.

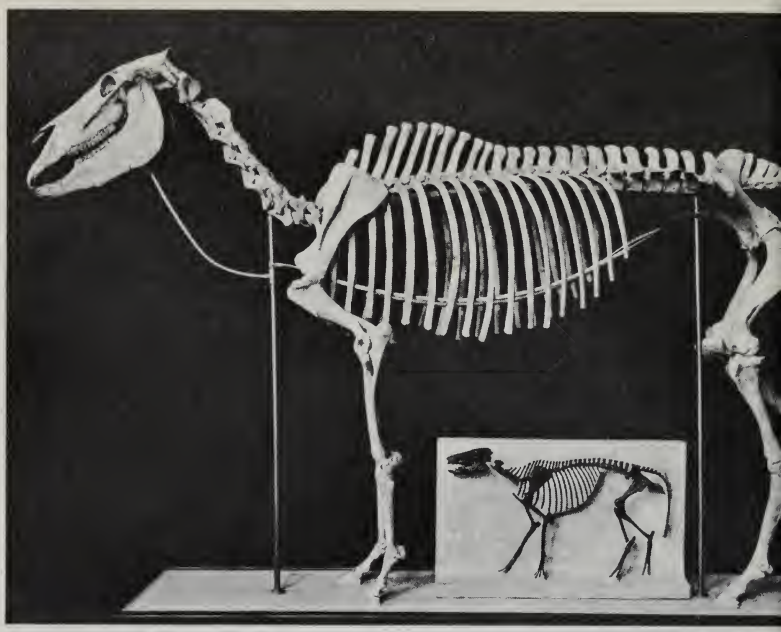
The multituberculates were small plant-eaters, equipped with chisel-like incisors and large jaw teeth. In size and appearance they may have resembled the modern woodchuck, though there is no relationship. The order died out early in the Eocene.

The marsupials were essentially similar to the modern opossum. Their distribution appears to have been worldwide.

The insectivores were small animals, very much like the modern shrew and porcupine. They appear to have been the ancestral group from which many modern animals developed. But they themselves stayed fairly much the same throughout mammalian history. They did not share in the general evolutionary advance.

The rodents were gnawers, such as rats, mice, and squirrels.

***Coryphodon*, an amblypod, resembled pigmy hippopotamus.**



Fossil skeleton of *Eohippus*, tiny "dawn horse," stands beneath skeleton of *Equus scotti*, a present day horse.

The primates were represented in the Paleocene by small half-apes, the tarsioids and lemurs. Most of them were scarcely larger than squirrels.

The creodonts of the Paleocene were the forerunners of our modern carnivores. At first a sort of generalized hunting animal, by the end of the Paleocene they began to show some further specialization, some of them developing dog-like, others cat-like, characteristics. They ranged from the size of a weasel to that of a bear. Although they must have been numerous, they have left a poor fossil record. By the end of the Eocene, having given rise to much more specialized killers, the creodonts as such became extinct.

The condylarths were strange creatures, indeed. They had a slender body, a perpetually arched back, and a long tail. In appearance they would have reminded one of a carnivore,

but each toe bore a small hoof and the teeth are clearly those of a plant-eater.

The amblypods were stocky and ponderous. They had thick-set, stout legs and blunt, five-toed feet, each toe bearing a hoof-like nail. Their canine teeth were long, sharp tusks, their cheek teeth small and low-crowned. At first no longer than sheep, they developed into larger forms, culminating in the Eocene in *Uintatherium.* Some of the uintatheres stood as high as seven feet at the shoulder, as large as a small elephant. The creatures bore three pairs of blunt horns, two pairs upon the nose and the third pair on the head. The males had dagger-like tusks in the upper jaws. An exceptionally small brain in relation to body bulk probably made them stupid animals even for their time.

At the beginning of the Eocene the ancestors of many modern groups, including the horse, rhinoceros, and camel, appeared simultaneously in Europe and North America. Perhaps all of them had developed somewhere in the northern land mass and had migrated southward by two different routes. The elephants first appeared late in the Eocene, but did not appear in North America until many millions of years later, migrating from Asia. The earliest elephants are known from North Africa, which appears to have been their ancestral home. Their skeletons are found in Late Eocene formations in the desert west of Cairo. They stood about waist-high to a man. All of the new forms, in fact, were small and some of them bore only faint resemblance to the larger life forms to which they were to give rise.

The titanotheres also appeared in the Eocene. While their name implies that they were giant beasts (which, in later ages, they would be), in the Eocene they were no larger than a sheep. By the Middle Oligocene they had developed into animals which, in some species, stood eight feet at the shoulders. Their brains, however, did not keep pace with their bodies

and they must have been incredibly stupid. They had the appearance of, and were in fact distantly related to, the rhino. They had thick, barrel-like bodies and huge heads with small, rhinoceros-like ears. On their noses they bore bony outgrowths which look like horns, but were not true horns, which branched in the middle and flared out at both sides.

While the titanotheres were large, they would have been dwarfed by another animal (this time a true rhinoceros) which stood 18 feet tall. Its fossil remains have been found only in Asia, and except for its size, there was nothing particularly spectacular about it. Named *Baluchitherium,* it is the largest land animal known to have existed. So far as is known it lived only in the Oligocene.

The fauna of the Eocene included the small titanotheres, tiny cameloids, bats, small primates, and a wide variety of creodonts. Some of these carnivores were cat-like, some dog-like, some hyena-like. In the early Eocene none of them were larger than a timber wolf. During the epoch, however, a number of them grew to the size of bears and one monster, *Andrewsarchus,* the fossil skeleton of which was found in Mongolia, had a skull two and a half feet long.

The first oreodonts appeared in the Eocene. These were sheep-size, long tailed, four-toed animals that persisted for millions of years, herds of them inhabiting the plains. Browsers and grazers, they were long-bodied and short-legged. They are not directly related to any living animal, but may have been a remote relative to the primitive camel. So far as is known, they were confined to North America.

In North America the lemurs and tarsioids disappeared, for some unknown reason, at the end of the Eocene, leaving the continent without primates until some 30,000 years or so ago, when man first came from Asia across the land bridge which existed at the site of the present Bering Strait.

And in the Eocene, for the first time, a most familiar animal

is now upon the scene—the rabbit, which has changed but little and is still in evidence.

To round out this quick survey of life in the Eocene, one more group of animals must be mentioned, the chalicotheres. They were fairly large forest-dwelling animals, resembling a horse in some degree. Their body was deep and short coupled and their feet were armed with mighty, wicked claws. But far from being weapons, the claws apparently were used for digging up thick roots and tubers, on which the creatures lived. They also probably ate leaves. The animal disappeared in North America and Europe toward the close of the Miocene, but survived in southern Asia and Africa into the middle of the Pleistocene.

By the time the Oligocene dawned many animals were becoming somewhat more modern in appearance. Many of the

Giant pigs were more than seven feet high at the hump.

old, strange forms were gone. Only one genus of the creodonts remained. In the place of these carnivores were several kinds of small dogs and both biting and stabbing cats. The amblypods and condylarths were extinct. There were more oreodonts than ever, ranging in large herds. Stupid titanotheres blundered and blustered and thundered over the landscape. True rhinos were present, but all of them probably were hornless. Small camels, peccaries, and tapirs now made their appearance. The horse which, back in the Eocene, had been the size of a fox terrier, now was the size of a collie dog. The rodents, which had developed rapidly in the Eocene, now were everywhere. In Europe the first mastodon stood a little over five feet tall.

One of the great landmarks of evolution, the appearance of grass, seems to have occurred in the Miocene. This is inferred by the fact that it was during this time that the grazing animals acquired high-crowned cheek teeth which grew throughout the animal's lifetime. These are the kind of teeth which would be required by an animal which exists on grass. There is evidence that during the Miocene the spread of prairie land, at the expense of forests, and a more arid climate, led to the wide development of grazing animals, with huge herds moving across wide tracts of grassland. The formation of a land bridge across the Bering Strait, between North America and Asia, made migration possible, with animals wandering from one land mass to another. During the Miocene there was, within many groups of animals, a rapid expansion into new genera and species and in many instances an increase in size. Horses were now the size of small ponies. The camels, which at first had been no larger than jackrabbits, now were in general the size of sheep, although a few species grew almost as tall as giraffes.

Oreodonts still were present in large numbers and the rhinoceros had increased in population. Giant pigs grew to the size of oxen and had skulls four feet long. The first elephants, weird creatures sprouting four tusks, ambled across the Bering

Hulking ground sloth, club-tailed *Doedicurus*, and armored *Glyptodon* all flourished in the Pleistocene epoch.

land bridge and were the first of their kind to set foot in North America.

During the Pliocene further migrations brought the true mastodon to North America. Horses during this period evolved rapidly, and the rhinoceros and camel still were abundant. The oreodonts, however, were extinct by the beginning of the Pleistocene.

The Pleistocene, which dawned about a million years ago, would have been a hunter's paradise. Giant game herds, comparable to those of Africa a hundred years ago, wandered over Europe and North America.

In North America at least four species of elephants were present. The Imperial mammoth of the southern Great Plains stood 14 feet at the shoulders. Another somewhat similar mammoth was at home in the basins of Arizona and Nevada. In the forest lands a species of mastodon browsed in vast herds and in the north the woolly mammoth held sway.

Sabre-tooth tiger used teeth to slash and stab prey.

Horses still ranged North America—there were at least 10 species of them, one as large as a big work horse. Seven species of bison roamed the plains. One of them, *Bison latifrons,* had a horn spread of six feet. Camels still were common, but the wild pigs which at one time had roamed the continent now were largely confined to Texas, Mexico, and Central America.

As might be expected with so much game, carnivores were abundant. Many of them were cats, including several species of sabre-tooths, and another very much like the modern lion in size and shape. Dire wolves, huge fellows as big as a timber wolf or bigger, hunted in packs. Bears showed up, apparently immigrants from Asia.

North and South America seems to have been separated during a good part of the Cenozoic. When the isthmus of Panama rose to connect them late in the Pliocene epoch, the fauna of the two continents began to migrate from one continent to the other.

Prominent among the migrants from South America were the glyptodonts and the ground sloths.

The glyptodonts were giant armadillos, some of which measured 12 feet in length. All were heavily armored, with a rigid shell similar to that which protects a turtle. The tail, too, was armored, but here the shell was arranged in rings, which allowed flexibility. The end of the tail bore a cluster of heavy spikes, making it a deadly weapon of defense.

The giant sloths were clumsy beasts the size of elephants. They were awkward creatures, short-legged and club-footed. Their ancestors had lived for so long in trees that they had developed long, curved claws for climbing and for holding. When they became too heavy to live in trees, they became land animals. But their long, curved claws made it impossible to walk on the soles of their feet, so they hobbled awkwardly.

Northern animals which migrated south across the isthmus into South America included the mastodon, horses, tapirs and peccaries.

During the glacial age which marked the Pleistocene many animals which normally lived in the north moved south ahead of the creeping ice. Muskox remains have been found in Arkansas and Utah. In Europe the reindeer, the woolly rhinoceros and the Arctic fox ranged into France.

While the mammals dominated the Pleistocene, and indeed the entire Cenozoic era, there was other life as well.

Fossils of huge turtles standing as high as a man's waist have been found in the rocks of Florida. Many other fossils of turtles, but none as large, are found in Oligocene and Miocene deposits.

The Cenozoic had many birds. By the Eocene most of the present orders were represented. All of them by now had lost the teeth their ancestors had carried in their bills. Scattered throughout the world were a number of species of large killer-birds, all of them flightless. In the Miocene a bird that stood eight feet tall and had a skull 23 inches long inhabited the Argentine pampas. The mighty, horse-size skull ended in a

strong, hooked beak. Undoubtedly it was the world's largest bird of prey, and would have been an ugly customer to meet. In the early Eocene in Wyoming another bird stood seven feet tall and had a stout neck and a head almost as large as its Argentine cousin. The moa, a bird that was 10 feet tall, but apparently a fairly gentle creature, survived into the present day and only a few centuries ago was exterminated by the natives of New Zealand.

In Africa the great game herds of the Pleistocene continued into the present day. Everywhere else they disappeared. They apparently existed up until about 10,000 years ago, but then were swept away in a great dying off which closely resembles the dying of the dinosaurs and the other reptiles at the close of the Cretaceous period.

The change in spear-points found associated with the campsites of ancient man in America would indicate that the mammoth started dying out about 11,000 years ago and had utterly vanished by 10,000 years ago. In the campsites dating back to 11,000 years ago, Clovis points are found in association with mammoth bones. In deposits dating a thousand years later no Clovis points are found, but in their stead modified points called Folsum points. And the Folsum points are in association with the bones of giant bison. Apparently by this time the mammoths had disappeared and the change in the type of points reflects a change in hunting habits. It would seem that the Folsum points must have been better engineered for bison killing than the Clovis points, which were larger and heavier and apparently had been designed for mammoths.

The horses disappeared from North and South America, but lived on in Europe and Asia. The camels vanished in North America, but still live today as llama and vicuña in South America. But everywhere in the world the mammoth and the mastodon died out. The sabre-toothed cat disappeared, the great cave bear vanished. Left behind were many animals which

Thick hair protected mammoth from intense cold of Ice Age.

had been present all through the Pleistocene, but the more spectacular of the beasts died out.

A great number of explanations have been offered to explain the dying out. Many of them are completely fantastic. None of them stand up under close examination. Catastrophes of one sort or another are suggested, but there is no explanation of why a catastrophe should be selective, wiping out one species and allowing another to survive. Disease is another offered explanation, but there is some reason to doubt that an epidemic would kill off such dissimilar creatures as the mastodon and sabre-tooth. It has been suggested that man may have killed off the animals. It is true that man in a few years almost exterminated the bison of the North American plains. But these were men with repeating rifles. It is highly doubtful that a few thousand hunters armed only with stone weapons could have made much of a dent in the Pleistocene fauna.

There is, at the moment, no satisfactory explanation. We know no more about it than we know about the disappearance of the dinosaurs at the end of the Mesozoic period.

17. ICE AGE

The World Grows Cold

THE EARTH began cooling off in the Eocene. By the beginning of the Pleistocene there came a time when, in certain areas, the snow fell and did not melt as fast as it fell.

The end of each summer always found some of the last winter's snow upon the ground. Year by year the snow grew deeper. The lower layers turned to ice, and snow piled upon snow and there was more and more ice underneath the snow.

The body of snow grew each year and in time became what is known as a glacier. No unusual fall of snow is needed to form a glacier—no more snow, perhaps, than will fall in any normal northern winter. All that is needed is that the snow accumulates faster than it melts. Back at the beginning of the Pleistocene this went on for century after century and the ice piled higher.

A cubic foot of ice weighs 52 pounds. Pile up a hundred feet of ice and the pressure at ground level is 5,200 pounds. Pile up a mile of ice and the pressure at ground level is 274,660 pounds, more than 137 tons.

Despite its brittleness, ice does not crumble under pressure. The pressure holds it together. But pile up enough ice, with

the resulting increase in pressure, and the ice will flow like pitch. Under a circumstance such as this, the ice would begin to flow outward from the center of accumulation.

Glaciers can be seen today in mountainous areas in many parts of the world. Both Antarctica and Greenland are covered by glacial ice. As a result we know a great deal about the behavior and the movement of glaciers.

In the Pleistocene, we had something of the same sort—continental glaciation, often called an Ice Age. It was not the first time there had been extensive glaciation. In other eras there had been continental glaciation in various parts of the world. Africa, Asia, and Australia all had had their glaciers. Even so far back as the end of the Precambrian there is evidence of continental glaciation.

During the Pleistocene, three major glacial centers formed in North America. One, known as the Labradorean, was located in Labrador, between Hudson's Bay and the east coast of Canada; another, the Keewatin, formed west of Hudson's Bay, approximately in the center of Canada, and a third, the Cordilleran, was located on Canada's west coast. A fourth, rather minor center of accumulation lay north of Lake Superior in northeastern Ontario, and was known as the Patrician Glacier.

In addition to the great ice sheets which formed in Canada, two others formed in the northern hemisphere. One centered in Scandinavia and spread, at its greatest extent, over northern Germany and eastward into north-central Siberia. A third center of accumulation was located in the highlands of eastern Siberia. Antarctica also was heavily glaciated, as was Patagonia at the southern tip of South America. Elsewhere in the world most mountains undoubtedly boasted monster glaciers.

In North America the Pleistocene glaciers moved as far south as the northern half of Missouri and stopped just short of the Ohio River.

As the ice built up in the various centers of accumulation,

Small valley glaciers merge as ice flows slowly downward.

it began to flow, under its own weight, out across the land. It did not move swiftly. On the average a hundred feet a year was a good gait for a glacier, although under varying conditions it could move either much faster or much slower, or might even retreat.

But like every other geological event, the glacier had time on its side. It had centuries, tens of centuries. And it had the weight and the pressure to urge it on, for in the center of the accumulation the snow still fell faster than it melted and year by year the ice grew, maintaining the pressure that moved the glacier on its way.

It was an irresistible force, but it did not act like one. It had "give" to it and it flowed and acted almost like a slowly moving tide of water. As it flowed over the earth it filled up the hollow places with rubble and with ice. It planed off the hills, it leveled heights of land; but when it came to something that resisted it, it flowed around it and, perhaps, later on, eventually overwhelmed it.

It collected great masses of boulders and pebbles and all other sorts of debris and pushed it all along ahead of it, or it overrode this assorted debris, embedded it within itself, and moved the debris along with it, sometimes in its lower layers, sometimes higher in its structure. It broke off ledges and gouged out great masses of rock and rolled or carried these along, and in time the rock became rounded, with all sharp edges worn off. That is why you never find a glacial boulder that does not look as if it has been smoothed, in some instances even polished.

A good many rocks were embedded in the very bottom of the ice and as the ice moved along, so did the rocks. As the glacier moved, these "teeth" of the glacier gouged and tore at the surface underneath the ice. There are many places in the world where a glacier can be tracked, the direction of its movement determined by the scratches, called striations, carved into the solid rock surface by the glacial "teeth."

Much of the rock which came into contact with the glaciers was ground into what is known as "rock flour" a rock powder as fine as flour. Caught between the pressure of the ice and the solidity of the underlying rock, the captured debris was ground between two gigantic millstones.

Much of the clay which today forms the basis of the fine corn lands of North America's Middle West, and elsewhere in the world, is composed of this rock flour which was ground slowly and thoroughly by the glacial mill.

During a good part of the time that the glacier was advanc-

ing, there would have been some melting. The ice on the front of the glacial wall would have melted during the slightly warmer periods, but the melting would have been slower than the forward movement of the ice, so the glacier would continue to advance.

But there came a time, as the weather became warmer, that the ice melted faster than the forward movement of the ice, and the glacier then retreated.

Actually, the glacier could not retreat. There was no such thing as a glacier backing up. All that it could do was move forward, in response to the pressure from the center of the accumulation that drove it along. But in those times when its forefront melted at a more rapid rate than its forward advance, the glacier did seem to retreat as the melting uncovered ground which had previously been covered by the ice.

Sometimes the melting lasted for only a short while, perhaps a few centuries. Then the temperature dropped again and the glacier moved forward once more, undeterred by melting. But there were times when the warmer weather persisted and the glacier was melted far back into the north. And at other times the ice would entirely disappear and for thousands of years balmy temperatures would prevail.

The climate of the Pleistocene (and remember that we still are living in it) seems to have been a see-saw affair. During the last million years, worldwide declines in temperature built up great ice masses which then pushed their way across the land. Four times the weather warmed up and the ice disappeared. The last such warming up, bringing about the retreat of the glaciers, came something like 10,000 years ago. Ice from the last glacial age, the Wisconsin, still remains on earth today, in Greenland and the Antarctic.

The periods between glacial periods are called interglacial periods. It seems likely that we now are living in the fourth interglacial period of the Pleistocene. The ice which at one

time covered much of North America and Europe has retreated and there is some evidence that the climate still may be slowly warming. If this is so, in a few more thousand years palm trees once more may grow in North Dakota and the earth once more may enter upon a long, long time of summer. But it may be that this is only a slight warming up, that we actually are not living in an interglacial age and that in a few more thousand years the ice may start creeping back again.

The present average temperature of the earth is 58 degrees Fahrenheit. At the depth of a glacial age the average may have been no more than 40 degrees. During the height of an interglacial period the average probably was close to 72 degrees.

There is no direct evidence of the height the glacial ice sheets attained in their relentless march southward. On top of some of the peaks in the White Mountains of New England are glacial boulders which were deposited there by the retreating ice. These peaks are 5,000 feet high. In other places there is evidence that the height of the ice was at least 4,000 feet.

In the center of the accumulations the ice would have been thicker. For one thing, the weight of it would have depressed the surface of the earth. It is estimated that during the height of the Ice Age the land in the Hudson's Bay area was depressed as much as 1,000 feet. The same situation was true, to a lesser extent, wherever the ice lay. The extent of the depression would depend upon several factors—the weight of the ice, the length of time it remained, and the structural strength of the surface underneath the ice.

Prior to the appearance of the first ice sheets much of the terrain over which the ice pushed its way was old land. Rivers, cutting away through the ages, had formed deeply-eroded, well-defined valleys. There would have been few lakes, for the erosion of thousands of years would have tended to cut channels which would have drained the lakes. High hills stood

above the river valleys, but gentle hills, rounded and smoothed by the long process of erosion.

The glaciers changed all this. They filled up the river valleys and changed the courses of the rivers. The new rivers, the ones which formed their channels since the last glaciation, have not, in many instances, had the time to carve out their beds to the depth of the old, preglacial streams.

The glaciers changed the face of the land over which they passed, but just how did they change it, what mechanics were employed?

First, of course, was the grinding action, which tended to plane off the surface of the ground over which the ice passed. There are places in Canada where one can see how the slowly-moving ice planed off all the irregularities of rock in the Canadian Shield and left behind it great areas of smooth and level stone.

But when the ice melted back as interglacial periods set in, new formations were imposed on top of this planed surface. As the glaciers retreated, they dropped their freight. Boulders, sand, pebbles, all sorts of trash that the ice had picked up, were released and deposited on the ground.

The melting of the glaciers resulted in a great deal of water. Not only was water running off the forefront of the ice, but streams of water came, as well, from underneath the ice. When the melt was well under way, the front of the glacier was honeycombed and giving up a vast amount of water. This water from the glacial ice carried away much of the debris which had been dropped by the glacier.

The most conspicuous glacial formations are the terminal moraines, groups of long ridges or rounded hills, representing the final resting place of the mass of debris which was pushed along in front of the glacier during its advance. The terminal moraines mark the furthest advance of the glacier.

A lateral moraine is a ridge of rock and soil which formed

Scored and gouged by glacier, Canadian Shield lies bare.

along the side (not the front) of a glacier. Ground moraine is rubble which, pushed along by the glacier, dropped into irregularities of the surface and remained there as the ice passed over it. "Moraine" is from the French and means a heap of stones.

Till plains are areas of ground moraine, where the melting glacier left behind the silt and rock flour, the pebbles and the boulders it was carrying. In certain instances these plains are so thickly strewn with boulders that they are called boulder plains.

Where the ground in front of the glacier sloped away from it, the melt water acted as a transport, carrying the debris out from the face of the glacier. This is called an outwash plain. The material in an outwash plain is graded—that is, the coarser and heavier particles of debris were dropped first by the transporting water, while the finer particles, such as sand and silt, were carried to the outer edge of the plain.

In many instances great blocks of glacial ice broke off the face of the glacier and became buried in the outwash plain. When the ice blocks later melted, pits were left in the plain, which then is called a pitted outwash plain. A number of small lakes owe their origins to such blocks of ice, the pits left by the ice being filled with water. The depth of such lakes usually does not exceed 30 feet, although there are some that have a depth of up to 70 feet. Such lakes often are known as kettle lakes, due to the fancied resemblance to kettles filled with water.

In many other instances lakes were formed when the glacial ice gouged their beds out of solid rock. This is true of Lake Superior, the ice plowing out an area of soft sedimentary rock, which had been laid down in the Precambrian, to form the basin of this largest inland lake in the world. Many of the Canadian lakes also were formed in this manner.

Other lakes were formed when glacial debris formed hollows in which the water could collect or where the debris acted as a dam which held back the natural flowage of the water.

The movement of the glacier from the north blocked all northward-flowing rivers, and in this way a number of glacial lakes were formed. Lake Agassiz, which at one time covered

much of Minnesota and North and South Dakota, was formed in this manner by the blocking of the Red River. The water from the melting glacier, unable to flow north, ponded in front of the retreating glacier to form a lake which at its greatest extent was five times larger than the present Lake Superior.

The great glacial lakes now are gone. They disappeared as soon as the glacier had retreated far enough to unblock their natural drainage outlets. But we still can read their history from their ancient beaches, which in many cases can be traced for miles.

The Great Lakes, the Finger Lakes of central New York, and many other chains of lakes were formed by glacial action, either by tongues of ice scooping out their beds or by the building up of dams by terminal moraines which impounded their waters.

Eskers, perhaps, are the strangest glacial formations. They resulted from streams which formed beneath the ice and which may have wandered about for a considerable distance before emerging from the front of the glacier. These streams carried sand and gravel and deposited it in their beds between the walls of ice. When the glacier melted away, gravel and sand ridges were left where the streams had flowed. These ridges are called eskers.

Another glacial effect you may run across is something known as an erratic. It is not a formation, but a boulder or a large chunk of stone which is entirely different from any rock in the locality in which it is found. It is a boulder which has been carried from the place of its origin by a glacier and deposited in geologically foreign territory.

Thus, in many ways, by the changing of river courses, by the formation of lakes, by the leveling of the land and the piling up of debris, the glaciers changed the face of that part of the earth over which they passed.

When the evidence of the Pleistocene glaciation was first

uncovered by science, it was believed only one period of glaciation, one great ice sheet, had been involved. But study of the glacial deposits showed that the glacial drift was separated by old soils and beds of peat that had been leached or decayed. In some instances these layers contained fossils of plants and animals which could only have existed in a temperate climate.

Thus it became apparent that there had been more than one ice sheet, and that long periods of temperate climate had been interposed between the rigorous climates which would have been necessary to form continental glaciers.

Further study revealed that there had been, in fact, four periods of glaciation, and that these periods were separated by long interglacial periods.

This applied to both North America and Europe and apparently also to the southern hemisphere, although that half of the world does not appear to have undergone anywhere near as much of glaciation as did the northern hemisphere. And, as might have been suspected, the North American and European periods of glaciation correlated in time.

Each of the North American and European periods of glaciation, and the interglacial periods, have names. However, the periods are named on different systems for the two continents. In the following correlation of the Ice Ages of Europe and North America, the latest is at the top, the oldest or first glacial period at the bottom of the column:

	EUROPE	NORTH AMERICA
Fourth Glacial	Wurm	Wisconsin
Third Interglacial	Riss-Wurm	Sangamon
Third Glacial	Riss	Illinoisian
Second Interglacial	Mindel-Riss	Yarmouth
Second Glacial	Mindel	Kansan
First Interglacial	Gunz-Mindel	Aftonian
First Glacial	Gunz	Nebraskan

When it comes to assigning dates to the several glacial and interglacial periods, we are only now beginning to stand on anything like solid ground. Up until a few years ago the best estimate was that the Ice Age began about one million years ago, with the Pleistocene epoch dating from the first glaciation. Studies of the amount of weathering and chemical decay which occurred in the glacial deposits during the interglacial periods seemed to give some indication of the time involved.

On this basis, not considering the 10,000 years or so since the Wisconsin glaciation began to melt back, geologists figured that the interglacial periods accounted for a total of about 645,000 years, considerably more than half of the million years assigned to the Pleistocene. These estimates assigned a length of about 200,000 years to the Aftonian interglacial period, about 310,000 to the Yarmouth, and about 135,000 to the Sangamon.

In 1964, however, a team of researchers at Lamont Geological Observatory at Columbia University announced an impressive investigation which seemed to show that the boundary between the Pleistocene and Pliocene epochs lay one and a half million years (rather than a million) in the past.

This study, which was based upon an investigation of deep sea cores, also gave a new calendar for the glacial and interglacial periods. The findings were derived from a study of the abundance of shells of certain species of our little friends the *Foraminifera,* in the cores.

A study of presently living foraminiferans shows that they are divided into three general groups: those confined to low (and thus warm) latitudes, those abundant in middle latitudes, and those which thrive in higher (and thus, cooler) latitudes. From this evidence it seems clear that the different groups of foraminiferans are limited in range by the temperature of the water. Thus, during times of a cold climate, there should

Core sample is examined on deck of research vessel.

be a southward shift in the range of the various groups of these little creatures, and in times of warmer climate a northward shift. Since the fossil shells of these little life forms make up a good part of the oceanic ooze, it was reasoned that a study of the deposits on the floor of the ocean, at varying depths, would provide an index to the weather of the earth over a long period of time. If in one section of core from the ocean floor shells of warmth-loving foraminiferans were found, it could be reasoned that during the time represented by the core the earth was warm. And if a few feet further down the shells were those of foraminiferans who were restricted to colder water, then there was good evidence that the warm climate had been preceded by much colder weather.

Working with a total of 3,000 cores, gathered on 44 oceanographic expeditions since 1947, the Lamont scientists matched 26 cores which provided an unbroken record of sea bottom deposits from the end of the Pliocene epoch.

The boundary between the Pliocene and Pleistocene epochs was determined by the disappearance of the discoasters, a tiny marine life form which became extinct at the end of the Pliocene, and by certain abrupt changes in some of the foraminiferans —changes which also date from the end of the Pliocene.

While the rate of deposits on the sea floor varies, the variations are always accompanied by variations in textures. Taking these variations into account, the Lamont team arrived at an average rate of accumulation of 2.5 centimeters (one inch) for every 1,000 years. Since the thickness of the entire Pleistocene section of cores measured 38 meters (a meter is 39.37 inches), the age of the Pleistocene would figure out to about one and a half million years.

Reading the core record in terms of the fossil remains of the various kinds of foraminiferans, the Lamont team arrived at this calendar for the glacial and interglacial periods:

The Nebraskan glaciation began about a million and a half years ago; the Aftonian interglacial interval lasted from about 1,380,000 years ago until about 1,200,000 years ago; the Yarmouth interval began about 1,060,000 years ago and ended about 400,000 years ago; while the Sangamon began about 320,000 years ago and lasted until 120,000 years ago, which would be the time at which the Wisconsin glaciation began.

Radiocarbon dating gives us a fairly accurate measurement of when the Wisconsin ice began its final retreat. While this dating varies slightly from locality to locality it sems fairly safe to say that the ice began to melt about 10,000 years ago.

At Two Creeks, Wisconsin, radiocarbon dating shows that the ice was still there 11,000 years ago and that it began to recede about a thousand years after that.

Other evidence, taken at different localities, seems to peg the retreat somewhere between 11,000 and 10,000 years ago.

From the figures given, it becomes evident that the interglacial periods extended over a number of years. If we are living today in a true interglacial period, we may confidently look forward to another 100,000 years of warming weather, perhaps even another 300,000 years before the next glacial period begins. However, there is evidence that during each glacial period there were glacial recessions, during which time the glacial ice melted back for a short time and then began to move once more. There are indications that during the last glacial period, the Wisconsin, the glaciers receded for 20,000 years or so, then came back again. It may be that we are living only in a glacial recession and that we have only another 10,000 years or so before another glacial period is upon us.

The history of the various glaciers is read by what is known as drift, the accumulation of debris which each of the glaciers left behind them. It is only by sheer good luck that it was learned some years ago that there had been four glacial periods. It so happened that each of the four succeeding glaciers advanced not quite as far south in some localities as the one which preceded it. Because of this we can read the edges of the glaciers, distinguishing the drift of one piled atop the drift of another.

Because lengthy interglacial intervals existed between each of the glacial periods, the upper layer of each mass of glacial drift was subjected to chemical change and weathering before another drift was superimposed upon it by another glacier. It is this changed character of the topmost layer of each drift that tells the story of the glaciers. The differences in the chemical changes and the weathering mark the boundary between the evidence of one glacier and another.

The first glacier, the Nebraskan, advanced across Iowa into Missouri and almost to the southern edge of Kansas. The suc-

ceeding glacier, the Kansan, extended only part way across Kansas, leaving the Nebraskan drift exposed along the southern edge of that state.

These glaciations, of course, extended deep over the eastern states and in the west as well, but as one might guess by the names given all four glacial periods, it is in the American Midwest that the best opportunities to study them have been found.

After the Kansan ice sheet came the Illinoisian which, in places in Iowa, Missouri, and northeastern Kansas did not quite cover the ancient Kansan drift. The Wisconsin, the fourth and last of the ice sheets, failed to overlap the Illinoisian drift along large areas of its southern exposure.

While the older drift areas show deep weathering, the Wisconsin drift is weathered in no place to a depth of more than three feet. In many places it still looks as it must have looked only a short time after the retreat of the ice. Nature has not had the needed time to round it off, to reduce it to gentle contours. Its boulders and pebbles still are fresh and solid. The outwash plains and the moraines are still visible to the eye that knows what to look for.

Small peat deposits are scattered through many of the older drifts, pinpointing the location of ancient swamps and bogs where the peat had formed from vegetation buried in the watery depths. Here we have, on a smaller scale, the same sort of operation that was carried out during the coal-building time of the Pennsylvanian period.

Of all the clues left behind in the drift, the peat deposits sometimes are the most instructive. From these, geologists can learn about the weather by studying the kinds of vegetation which grew during the interglacial intervals.

Analysis of pollen found in the peat beds gives a somewhat better than good guess as to the climate of the period. Pollen from each tree and plant is recognizable, and by knowing what

Extent of early glaciations in North America.

kinds of trees or plants grew near the peat beds something can be learned about the weather.

The Pleistocene ice sheets are estimated, at the times of their greatest advance, to have lowered the ocean levels by some 300 feet. This can be explained by the fact that the glaciers soaked up so much of the earth's water to form the continental ice that there was considerably less liquid water in the world.

The lowering of sea levels made dry land out of many shallow seas. England, during those days, was a part of Europe; Borneo and Sumatra were a part of Asia, and Alaska and northeastern Siberia were united as the lowering of the sea

Last glaciation in North America, the Wisconsin Stage.

level made a land bridge between the two. It was over this bridge that man first came to the Americas.

Not only were the sea levels lowered, but the land underneath the ice was depressed, perhaps from several hundred to a thousand feet. The weight of the piled-up ice was more of a massive factor than can readily be realized, and even the solid earth gave beneath the pressure.

But once the glaciers melted back, the land began to rise again. In some parts of Canada and northern Europe, particularly in Finland, it is still rising. And this upwarping has left a number of unmistakable records. Beaches of the glacial Lake Algonquin, which once lay over much of the area covered by

Extent of early glaciations in Europe.

the Great Lakes, now stand some hundreds of feet above present lake level in western Michigan. During the time of the retreat of the Wisconsin ice, these beaches had been at water level or only slightly above it. At North Bay on Lake Huron, the watermarks of an ancient beach stands 1,150 feet above sea level. The beaches of glacial Lake Agassiz show an upwarp of some 400 feet in Manitoba.

When the Wisconsin ice melted back from the St. Lawrence valley, the area was so depressed that the sea rushed in and for a time the St. Lawrence was an arm of the Atlantic Ocean. Fossil whale skeletons dating from this time have been found in Michigan. At Daveluyville, which is some 60 miles southwest

Last glaciation in Europe, the Würm Stage.

of Quebec, a skeleton of a whale was found some years ago at an elevation of 275 feet above present sea level.

During the course of this brief survey of Pleistocene glaciation, we have seen how a glacial age came about and how glaciers behaved and what changes they wrought upon the land.

There is one other question: Why did they come about? What change in the earth brought about the conditions which resulted in glaciation?

To that question there are many possible answers. One of them may be right (although we don't know which one), or it may be that no one answer is correct. There may be many contributing factors, all of which, taken together, set up the circumstances which bring about an ice age.

While the sun appears to be a stable star, there is a possibility that over long periods of time there may be variations in its radiation. All the heat and energy which we have on earth originates with the sun. So even a small variation in the heat of the sun might cause a considerable difference in conditions on the earth.

If the sun, toward the end of the Pliocene, should have begun to supply less radiation, this might have been enough to bring about an ice age. It may be that the sun is in a period of long-term fluctuation, and that it is this fluctuation which brought about the successive glaciations during the Pleistocene.

There is some evidence that even today (and thus in relation to short-term fluctuation) glaciers retreat during periods of great solar activity, and tend to grow when solar activity falls off. There is, as yet, nothing too sure about this correlation, but there is enough evidence so that it can be suspected.

Variation in solar radiation also may have some influence on the jet streams which blow high above the surface of the earth and which help to set the pattern of our weather. Once again, any pronounced change in these jet streams, caused by solar influence, could bring about an ice age.

Or the answer may lie with carbon dioxide. Carbon dioxide acts, in regard to the earth, much as glass acts in regard to a greenhouse. In a greenhouse glass allows the infra-red radiations from the sun to enter the greenhouse, but retards the radiation from the greenhouse of the heat which is carried by the infra-red rays. Carbon dioxide operates in the same way in the atmosphere, allowing the infra-red radiation to reach the surface of the earth, but retarding the radiation of heat back from the earth. This carbon dioxide mechanism is called the greenhouse effect.

Thus, if something should happen which would decrease the amount of carbon dioxide in the atmosphere, more heat

would radiate back into space, the climate would grow colder, and an ice age could come about.

We know that we are having now (and that we have had through a great part of the Pleistocene) an unusual climate. For the greater part of its existence, earth has not been like it is today. Most of the time earth has had a mild and equable climate, an almost eternal summer, a climate without seasons.

So let us go back to a time when something might have happened to the carbon dioxide balance. Back in the Pennsylvanian period lush forests grew in the coal swamps and were deposited as coal. Could it be, it has been asked, that the deposit of our coal could have broken the carbon dioxide balance, the lush vegetation sucking many tons of it out of the atmosphere and depositing the carbon as coal? On the face of it, the idea has some possibilities. But it doesn't stand up under examination. For it is a long time from the Pennsylvanian period to the Pleistocene epoch, more than 300 million years, and between the time of the coal forests and the day of the glaciers the earth enjoyed mild weather for millions of years.

Another theory that has been advanced is the so-called dust theory. Usually it takes the form of a suggestion that a cloud of cosmic dust drifted into the area occupied by our solar system, or that our system moved, or is moving, through such a cloud. If this were the case, the dust would cut down the solar radiation which reaches earth. At other times the speculation fastens on the possibility that clouds of dust were thrown into the atmosphere by volcanic action. Such dust, if present over a sufficiently long time, would have the same effect. Anything which would cut down the amount of solar radiation reaching the earth might lower the temperature sufficiently to bring about glaciation.

The most recent theory, and the one which at the moment appears to be best grounded, is the Ewing-Donn theory, put forward a few years ago by Maurice Ewing and William Donn,

of Columbia University. They believe that the earth's temperature is due to an internal, self-regulating mechanism rather than to any variation in solar radiation.

Their theory centers upon the situation of the Arctic Ocean.

They point out that the Arctic is practically a landlocked ocean. Its only opening to the Atlantic is over a shallow sill which runs between Greenland and Iceland and north to Spitsbergen.

When extensive glaciation locks up a good deal of the oceanic water in ice masses, the oceans are lowered and the warmer currents of the Atlantic cannot get over the sill to mix with the Arctic waters. As a result, the Arctic Ocean freezes over, as it is now frozen. When it is frozen over, there is less moisture in the Arctic regions to produce snow. With less snow falling, glaciers cannot grow and the ones that are in existence recede.

But as the glaciers melt, the ocean level rises, the warm Atlantic waters can get over the sill, the Arctic ice thaws, the polar ocean becomes open once again, there is a great deal of moisture rising from its surface, which in turn produces more snow, and the glaciers begin to form again.

If you are the worrying type, here is something to worry about: The Arctic ice, studies show, now seems to be getting thinner and thinner. If it continues as it is going, the Arctic may be an open ocean within another few thousand years, perhaps another few hundred.

If the Ewing-Donn theory is correct, then the likelihood is that the Ice Age will continue until there is some geological change of rather massive proportions to alter the characteristics of the Arctic Ocean. With the freezing and the thawing of the ocean, the continental glaciations will wax and wane through perhaps several more millions of years.

And if this is true, and there is another continental glaciation, what can man do about it?

It is not something that any of us who read this book need to worry about, nor our children, nor our grandchildren. If it comes, it will be many generations in the future.

If another continental glaciation should occur, man will be forced to retreat southward as the animals of the Pleistocene were forced to retreat before it. The world's population will be squeezed into less living space. A renewal of the Ice Age would rob us of much of our productive farm land, the American Middle West, the farm lands of Germany, the plains of Poland. Canada and the north of Europe would be covered by ice. All of the northern cities would be gone, ground to bits beneath the ice.

That's the dismal side of the picture. There are certain compensations.

The growth of the glaciers would soak up an immense amount of the earth's water budget. The seas would recede and much land would be gained. In America, New York (which might stand on the edge of the ice and still be spared) would stand far inland, and thousands of acres of new land would extend eastward from the present Atlantic coastline—new and extremely fertile land. Melt water from the glaciers would provide plenty of water for the irrigation of those vast stretches of land in the western United States which now are too arid to be much good agriculturally. It is likely, too, that the prevailing westerly winds would shift southward with the advance of the glaciers and would bring more rain to this same arid land. The American southwest and the Sahara Desert might become productive one again.

The advance of the ice would be slow. Men would have centuries of warning and plenty of time to make any social or economic adjustments that might seem necessary.

If another glaciation is to occur, thousands of years will pass before the ice begins to build up again. More thousands of years will pass before it builds to a point of actually starting

to move. And more thousands of years will pass before it reaches heavily populated areas. There will be all sorts of time in which man, if he is able, can do something about it.

By that time man may have learned to so modify and control the weather that he can nip the new glaciation in the bud, can stop it before it gets a start. Or, if he can't do that, he may be able to devise some way in which he can fight it, some way to melt it faster than it can advance.

At the moment there is no suggestion of how this might be done. The whole idea, as of today, seems just short of ridiculous. But a hundred years ago no one had thought of nuclear energy, no one had dreamed that within another century man would be thinking of landing on the moon. If man's technology continues to develop, he'll more than likely have a way to beat the glaciation, the next time it comes.

However frightening it may sound, the possibility of another glaciation is one thing that we cannot, now, with much profit, concern ourselves about. We can only anticipate that man of the future, smarter and more knowledgeable (and perhaps even wiser) than we are today, may find himself able to cope with the situation should it come.

Rather, perhaps, we should take a look at the advantages which have been visited upon us by the recent glaciations.

At the time the first Pleistocene glaciation began, the earth was an old and deeply eroded land. Its soils probably had been leached out and would not have been too productive. Little mineral content would have remained in the soil to make it productive.

Then the glaciers came and swept away this old and leached-out soil, leaving in its place a new material which in time would develop into new and highly fertile soil, rich in mineral content.

Glacial action also served to level off the land, grinding down the high points, filling in the areas of deep erosion, giving

us a level land more easily farmed than would have been the ancient surface which existed before the glaciation. The agricultural potential of those areas over which the glaciers passed has been increased considerably by the glacial action.

Nor is farm land the only economic consideration stemming from glaciation.

Extensive sand and gravel deposits were left behind when the glaciers dumped their loads of debris, giving the glacial areas material for road construction and other commercial purposes.

The old pre-glacial terrain probably had few lakes. Millions of years of erosion had cut out channels that would have drained most of those that at one time had existed. But the retreating glaciers left behand them thousands of lakes which today makes many glacial areas famed resort and vacation countries.

And in North America the action of the glaciers in scooping out the basins of the Great Lakes gives us today a great inland waterway, with ocean steamers docking at Duluth at the head of Lake Superior.

It may be that within another fifty thousand years or so an old and eroded and worn-out northern hemisphere could use another glaciation.

The possibility exists, however, that man, without trying to, without knowing that he was doing it, has brought an end to the Ice Age.

A while back we mentioned that any process which would have removed some of the carbon dioxide from the atmosphere would have caused the world to grow colder and brought on an ice age. The same situation would work in reverse, as well. Anything that operated to put a greater percentage of carbon dioxide into the atmosphere would cause an increase in the earth's mean temperature and would put an end to any possibility of another glaciation.

And man, since the Industrial Revolution, has been adding to the amount of carbon dioxide in the atmosphere by the burning of coal and oil. He is, in effect, by burning such fossil fuels, returning to the atmosphere much of the carbon dioxide which was taken from the atmosphere during the Pennsylvanian period and other coal-making times.

Only a very small increase in the carbon dioxide content of the atmosphere would suffice to raise the world's temperature enough to prevent another ice age. A rise of no more than 3 or 4 per cent in the earth's mean temperature not only would prevent new ice from forming, but would melt the present ice. It would take a long time, of course, to melt all the ice in the world under such a circumstance, but if the temperature of the earth were to increase appreciably, that is what would happen.

During the twentieth century we have poured thousands of tons of carbon dioxide into the air in the form of gases from burning fossil fuels. Whether this has resulted in any appreciable increase in the amount of carbon dioxide in the atmosphere is at the moment a matter of study. The ocean has the capacity to absorb all the carbon dioxide that man may be able to release into the atmosphere. The question is whether the ocean is able to absorb it rapidly enough to prevent its building up in the atmosphere. If the ocean is absorbing it as fast, or almost as fast, as we are introducing it into the atmosphere then the world's climate will not change. If it is not, the greenhouse effect will increase, the world's temperature will creep up, and the possibility of another world glaciation for many thousands of years would be eliminated.

18. MAN

The Triumph of Intelligence

TOWARD THE END of the Mesozoic era certain little mammals may have taken to the trees, driven there by the necessity to keep out of the way of the ferocious reptilian life for which they were no match and many of which, more than likely, were in the habit of making a meal out of any mammal they ran across.

Once up in the trees and out of the reach of the predators, these little animals made themselves a new life and this new way of life began to modify their bodies.

So long as they remained ground animals, there had been no need for the modification of their limbs. They had padded along, flat-footed, their four legs acting as a means of locomotion and as a support for their bodies.

But once they climbed into the trees, there was a need for the specialization of the limbs. The front paws gradually became hands, equipped for grasping and for holding, for climbing and for swinging through the branches. The front legs gradually became arms, no longer mere supports for the body, but designed to reach upward and outward. The hind legs, forced more and more to support the entire weight of the body,

became thicker and more heavily muscled, not only to support the weight of the body, but to provide the strength which would project the body forward in leaps from one branch to another.

As has been emphasized time and time again, such changes did not occur quickly. They came as a result of a very deliberate process of evolution, requiring a long time for the specialization to reach its logical conclusion.

Another specialization was concerned with a shift of emphasis in the basic senses. So far as ground animals are concerned, the sense of smell is of vast importance. It is required for smelling out food and for identifying friends and enemies.

But once our little animals had taken to the trees, the sense of smell became somewhat less important. There was no longer any need to go sniffing along the ground in an effort to locate food, or to continually test the breezes for scents of possible enemies—these creatures had retreated into the trees to get rid of enemies. A few might still remain, of course, but nothing like the number there had been at one time.

What did become immensely important to the tree-dwellers was the sense of sight. Better coordination of the body in swinging through the treetops, in running out along a branch, in jumping from one branch to another, depended in great part on better eyesight and better judgment of distances.

In the ground animal the nose is carried well to the front of the body, at the end of a snout. The eyes, because of the forward thrusting of the muzzle, do not work together, but look out independently on either side. Because of the lessened importance of the sense of smell, the snout of our tree-dwellers receded and the face gradually became flattened. With the snout out of the way, the eyes now were able to look forward. Working together, they afforded their owner the advantage of binocular vision, giving a greater sense of proportion and of depth. This enabled the animal to see things in their true relationship and to have a better judgment of distance.

A third development in the tree-dwelling animal was the enlargement of the cerebral cortex, that portion of the brain which receives and correlates the impressions gained from the various sense organs, weighing them one against another and making a judgment so that the motor nerves may make an appropriate response. Coordination of action is necessary in any animal living in the treetop world, and the enlargement and development of the cerebral cortex provided this.

So far as we are concerned, this development was the most important of the lot, for from it springs the capacity for intelligence which has made man foremost among the mammals. The development of the cerebral portion of the brain not only made it, at the time, easier for our little animals to get around in the trees; it also was the beginning of a development which has made possible the complex patterns of abstract though which mark the human being.

Another thing that happened was a decrease in the birthrate of the tree-dwelling animals and an emphasis on the care which must be given the young. Among ground animals litters of up to a dozen or more are born at a time. Within a fairly short time these young animals are able to shift for themselves, requiring a minimum of motherly care. But in the treetops a mother animal would have a rough time taking care of a dozen young. At the same time, young animals in the treetop world would require more care than would the young of ground animals. As a result, fewer young were born, and they were cared for by the mother for a longer period of time. Better training of the young took place through longer association with the mother.

The treetop animals probably took to the trees about the end of the Mesozoic era; by the Eocene epoch of the Cenozoic era they had given rise to a number of different kinds of tree-shrews, lemurs, and tarsioids. By the Oligocene these had given rise to the early forerunners of monkeys, apes, and men.

Two ape-like or "near-ape" fossils are known from the Oligocene. Both fossils, unearthed in Egypt, really aren't much to get excited about. In each case only a single jawbone of the animal has been found. But a study of the teeth makes it seem likely that here we are dealing with a far ancestor of the ape.

The first true apes are known from Miocene fossils. Most important of these animals is *Proconsul,* which lived in Africa. Rather than a single animal, *Proconsul* is a genus, represented by a number of fossil species. The smallest of these can be compared to a small chimpanzee, the largest to a big gorilla. There is, in fact, a good possibility that *Proconsul* is the ancestor of the modern chimpanzee and gorilla. He cannot be consid-

Skull of *Proconsul,* discovered in Kenya in 1948.

ered a direct ancestor of man, but he probably was not far from man's line of descent. Somewhere, during this time, must have lived another animal, a cousin of *Proconsul,* which was man's remote ancestor.

A much close relative of ours is *Oreopithecus,* the so-called "mountain ape" whose fossil remains have been found in Italy. While there is a tendency to group this animal, which lived during the Pliocene, with the great apes rather than regarding him as man-like, there still exists a possibility that further study will reveal it as hominid, on the same line of descent as man.

While the forerunners of the primates (the order to which both apes and men belong) took to the trees at the end of the Mesozoic era, and developed there those characteristics which gave rise to the primates, there came a time when their far descendants had to return to the ground again, too heavy of body to remain living in the trees. *Proconsul* probably lived most of the time on the ground, although occasionally, as necessity demanded, he may have been able to go back into the trees. *Oreopithecus* probably spent a good part of his time as a ground animal.

In most cases this return to the ground was marked by at least a modified return to four-legged traveling. The baboons, for example, walk and run on all four legs, but in sitting can use their arms and hands as manipulatory organs. The same applies to the gorilla and to a lesser extent to the chimpanzee which, while its normal gait is four-legged, is more apt to walk erect on its two hind legs than most of its cousin apes.

Man's own bipedal stance, walking on his hind legs, has historically been attributed to the necessity of freeing his hands for the carrying or the use of weapons or tools. A new school of thought on this, however, appears to be gaining ground. It is now believed in some quarters that man gradually assumed his erect stance, not to handle tools, but to handle food.

At one time, it is believed, man probably was an eater

of carrion among other things. He grabbed food wherever he could find it. He may have made a practice of robbing the kills of great carnivores—after the carnivore had left, of course. But there was a chance that the lion or the sabre-tooth, or whatever it might be, would be coming back. In this circumstance it would have been foolhardy for the man to stay at the kill and eat his meal. So what he probably did was to collect as much of the meat as he could manage and scamper off with it, forced to run on his hind legs because his arms were filled with meat.

Or he may, on other occasions, have gathered as much fruit or as many roots or nuts as he could find and carried them off to some place where it would be safe to eat them In all these ventures he would have been forced oftener and oftener to walk on two legs only. Over many generations, certain physical evolutionary changes would have made it easier and easier and more normal and natural to walk upon two legs. In time man would have become a true bipedal being.

Bodily weight was one factor, undoubtedly, that made certain of the apes come down from the trees. There undoubtedly were other reasons, as well. Seasons of drought or a change in climate probably resulted in fewer forests and more grassland in certain areas. As the forest progressively disappeared, living space for the forest dwellers would have become more restricted, and some of them may have been forced to try out a new environment. Or it may be that there is an inherent tendency for any life form to fan out and cover as much territory as it can. Another consideration is that the reason for the retreat into the trees, the danger from the reptilian life of the Mesozoic, had long since disappeared. There still were carnivores, of course, but on the other hand the primate had, himself, become a far different kind of creature from the little animal that had first fled into the upper reaches of the forest. Not only did he have more heft and muscle; he also had developed

a highly organized brain that gave him a distinct advantage over the killers of his day. He had a new set of survival techniques and he may have returned to the ground simply because it now was safe for him to do so—and, perhaps, as well, because life on the ground now was easier than life among the trees.

The primates came down from the trees with limb specialization, brain specialization, better eyesight, greater bodily coordination, and the beginning of a social order.

What more was needed to make man possible?

An erect stance, for one thing, and we already have shown how that might have come about.

Speech, for another.

Many animals communicate in a limited way by sound or by display techinques. No other animal but man, with the possible exception of the dolphin, has developed a complex system of communication in which not only rudimentary information is transmitted, but abstract thought can be expressed.

Intelligence of a higher order and the need to express conceptual thought which such intelligence made possible may have been the motive which forced man to arrive at speech. Certainly, as he developed, he had more to talk about than the other animals—more to say than merely a sound of warning or a series of grunts or calls to transmit the information that food had been located.

But aside from this, there is one modification of a physical characteristic which helped enable man to talk. A ledge of bone called the "simian shelf" is found inside the front portion of the lower jaws of monkeys and apes. In man this ledge of bone is absent. Its purpose, in the other primates, is to strengthen the joint between the two halves of the lower jaw. In man this strength is supplied by a ridge of bone on the outside of the jaw—the bone that gives us a chin. The absence of the simian shelf gives man's tongue more room and flexibili-

ty, making speech considerably easier so far as the sheer mechanics of it are concerned.

The ability to talk, the ability to walk erect, went far toward the shaping of a man. There was, however, one other factor that was needed—the making and the use of tools.

Man is not the only tool-using animal, nor the only tool-making animal. Chimpanzees, in captivity, have fashioned tools—fastening two sticks together to knock down a bunch of fruit placed out of their reach.

But man was the first and only animal to make and carry a tool against a future need. Here we see that the distinction is not so much in the ability to make or use a tool as it is in the intelligence which can foresee the future need of one.

By exactly what path man came to speech or the consistent use of tools, we do not know. Perhaps in both instances the time required was long. Both required an evolution in thought and intelligence rather than in bodily characteristics, and the road to either could not have been easy.

But finally a creature stood forth that could be called a man.

Two groups of primate fossils from early in the Pleistocene give us the first solid evidence of man's line of descent.

The australopithecines, a group of near-human or prehuman primates, lived in Africa. There is a good possibility that the creatures were closely related to our own ancestors.

The pithecanthropoids, another group of fossil primates, who lived in Asia, represent true men and probably are in our direct line of descent.

While the australopithecines may not be the direct ancestors of man, it would seem that they represent at least one of the evolutionary forms through which the line of humanity must have passed.

They were small creatures, about the size of modern pygmies. They walked erect and are believed to have used simple

tools. In caves where they made their homes, great litters of animal bones have been found. Some of the baboon skulls found in the caves show signs of having been bashed in with some sort of weapon. Apparently almost anything that lived was meat to these little men. In addition to the skulls of baboons, the caves have yielded bones of tortoises, bats, birds and antelopes.

At the time the australopithecines lived in Africa, some 600,000 years ago, their home territory must have been largely grassland. Out in the open plains it would have been difficult for a single man to hunt down an antelope. Therefore it is believed that these little primates must have hunted in packs, which would mean they had a kind of tribal or family society.

They were not too intelligent. The average size of their brain is measured at 600 cc. (cubic centimeters), with a maximum of 750 cc. This is about the size of a modern ape brain. But since there is a direct ratio between body size and brain size so far as intelligence is concerned, the fact that the australopithecines were small may mean that they were more intelligent than they would seem at first consideration.

While cranial capacity—the cubic centimeters of space inside a skull—is an indicator of intelligence, it is not the only consideration. Our ancient men or near-men in all cases had a forehead that receded, leaving less room for the forefront of the brain. It is this forepart of the brain which is the seat of true intelligence, and therefore the shape of the skull, as well as its capacity, has some bearing on possible intelligence. Because of this, it often is difficult to gauge true intelligence in fossils.

While there is no way of knowing if the australopithecines had speech, we do know that they had the physical capacity for speech, for there is no sign of the simiam shelf in their lower jaw.

The pithecanthropoids of Asia include both *Pithecanthropus*

erectus, Java man, and *Sinanthropus pekinensis,* Peking man. A number of fossil remains of Peking man have been discovered in the vicinity of Peking, China, but only fragmentary fossils of three individuals of Java man. Yet there seems to be no question that the two men belong to the same genus, and the weight of evidence would indicate they are in the direct line of descent of *Homo sapiens,* modern man.

Outside of Asia some pithecanthropoid fossils have been found in both Africa and Europe. These finds, however, are chiefly valuable only in showing that the pithecanthropoids had wide distribution.

The best estimate is that the pithecanthropoids lived between 500,000 and 200,000 years ago. Unfortunately, no more precise dating can yet be made. It seems, however, that the pithecanthropoids flourished at about the time the australopithecines were beginning to decline.

On the basis of what little is known of him, the brain capacity of Java man would seem to be about 860 cc. The brain capacity of Peking man, averaged out from five skulls, figures to 1,075 cc. This compares with an average of 1,400 cc. for modern man.

To us today the pithecanthropoids would appear brutish. Their faces ran to snoutiness, and prominent frontal ridges of bone above the eyes met above the nose. Both the chin and the forehead receded. The back of the skull tended to be pointed rather than rounded. Their necks were thick and heavily muscled.

But they unquestionably were men.

They walked erect and, in the case of Peking man at least, had tools and fire. There is no evidence of either tools or fire for Java man, but this does not necessarily mean he lacked them. The evidence for Java man is skimpy, indeed.

A long tradition of tool-making is in evidence for Peking man. Rocks, most of them quartz, found far from home, were

lugged to the home cave as raw materials for tools. And the tools are not merely weapons, but household implements such as choppers and scrapers as well.

Peking man was a successful hunter; large quantities of animal bones have been unearthed in association with his living quarters, many of them split open to get at the marrow. Charred bones indicate that he used fire for cooking as well as for warmth and protection against prowling predators. And some of these charred and split bones are human, giving some cause for belief that he was a cannibal.

There is no question that these two early types of men were, in the case of the pithecanthropoids, true men, and in the case of the australopithecines, near-men, and perhaps even true men. But the story is not yet all told, and in a few years from now it may have to be rewritten.

Dr. Louis S. B. Leakey, who for a number of years has been uncovering an astounding array of data at Olduvai Gorge in northern Tanganyika, in 1964 announced the finding of another ancient man, which he named *Homo habilus.*

A little creature, no larger than a modern-day pygmy, *Homo habilus* lived some 1,820,000 years ago. He made and used weapons, was a successful hunter, constructed rough shelters or wind breaks. Dr. Leakey is certain *Homo habilus* is much more closely related to modern man than either Java man or Peking man.

And if this is so—and at the moment there is nothing to suggest it isn't true—we have finally found the true ancestor of man in much deeper reaches of time than a few years ago we would ever have expected.

Two other types of men appeared on the scene in more recent times, and these must be mentioned to round out this sketchy picture of the rise of mankind.

The first of these were the Neanderthalers, undoubtedly men and probably not half the brutes they often have been

Reconstruction of skulls of *Pithecanthropus erectus* (left) and Neanderthal man (right).

pictured. They probably represent a divergent line of descent from pithecanthropoid ancestors, true men, but not quite the same sort of men as inhabit the earth today.

Many Neanderthal fossils have been found, and we know that at one time they inhabited much of Europe and the Near East. The evidence seems to be that they existed from about 250,000 years ago until about 40,000 years ago—perhaps longer than that.

Neanderthal man was stocky, broad of shoulder, thick of neck. He had a bulging brow ridge and his nose was a large protruding beak. His head was large in proportion to his body, and his forehead and chin receded. His brain capacity was as large as ours or larger, but because of his receding forehead his intelligence could not have been the match of ours.

He was an accomplished tool-maker, he knew the use of fire, he wore furs and animal hides to protect himself against

the cold and rain. And, what is more, he apparently had developed a concept of religion. There is evidence of a Neanderthaler bear cult and he not only buried his dead, but buried objects with them—apparently in the belief that they would need these objects in the Neanderthaloid version of an after-life.

But he not only paid reverence to his dead; he took care of the living, too. In many primitive tribes the old and sick were put to death as a matter of convenience. Not so with the Neanderthals, or, at least, with some of them. One Neanderthal skelton, found in a burial pit, gave evidence of having been crippled by arthritis and had only two teeth left in his mouth. Some one, it is clear, must have cared for him, found soft food that he could eat (may even have chewed the food for him before it was put into his mouth), and when he died gave him burial. Another skeleton shows evidence of having been born with a withered right arm which at sometime during his life had been surgically amputated. There are other instances, as well, which bear evidence of true humanity in the savage heart of the Neanderthaler.

The fate of the Neanderthalers was sealed with the appearance, perhaps 40,000 years ago, of modern man, *Homo sapiens*. Where *Homo sapiens* came from is not entirely clear. It is possible he might have risen and developed in Africa—no one really knows. All that we do know is that he burst upon the scene in Europe with what would now appear to be dramatic suddenness, wiping out the Neanderthaler culture that existed there.

How long Neanderthal man stood against the newcomers can not be guessed, nor do we yet know by what process the old race disappeared. There may have been open warfare between the two, with the Neanderthalers finally slaughtered to the last survivor. Or *Homo sapiens* may simply have frozen out the Neanderthalers, taking over the best hunting ranges and the best living areas so that the Neanderthalers died out

for the lack of a decent economic basis for existence. Or the two races may have interbred, with the Neanderthaler stock genetically absorbed in the larger population of *Homo sapiens*.

But whatever the answer, as time went on only one type of man remained and the way was finally clear for the greatest mammal of them all to assume dominance of the planet.

Once the dominant life had been the trilobites and the trilobites died out. Once the amphibians had been the dominant life and they remain today as only a few insignificant life forms. Once the dinosaurs roamed across the land, unquestioned masters of the scene, and then, suddenly, the dinosaurs were no more.

And man?

As a dominant species he has existed for something less than a million years. If we measure the probable span of his dominance by the span of time covered by other forms of dominant life, he still has many millions of years before he, in turn, may become extinct.

If he should become extinct, what process of evolution will determine his final disappearance? Will he become so specialized that he will box himself into an evolutionary corner? Or will he simply grown old and feeble as a race? Or will something come along to supercede him?

And you ask, in wonder, what could supercede him? What can beat intelligence?

We don't know, of course. But the evolutionary process through the ages has given evidence that it is never at a loss to produce new life forms or to introduce new survival values. There is no reason to believe, on present evidence, that in man an evolutionary dead-end has been reached.

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